EUROPEAN COMMISSION
DIRECTORATE-GENERAL
Joint Research Centre

Institute for Environment and Sustainability

Workshop Proceedings of the

"2nd International Workshop Thin Films in the Photovoltaic Industry"

9/10 November 2006

Editor: A. Jäger-Waldau

Scientific Technical REFERENCE System on RENEWABLE ENERGY and ENERGY END-USE EFFICIENCY

2007 EUR 22630 EN

Workshop Proceedings of the

"2nd International Workshop Thin Films in the Photovoltaic Industry"

held at the EC JRC Ispra, 9/10 November 2006

Chairperson: Bernhard Dimmler and Arnulf Jäger-Waldau

Editor: A. Jäger-Waldau

Co-organised by

EUR 22630 EN

Luxembourg: Office for Official Publications of the European Communities, 2007

Printed in Italy
ISSN 1018-5593 - EUR 22630 EN

PREFACE

This are the minutes of the 2nd International Workshop "Thin Films in the Photovoltaic Industry" held at the European Commission's Joint Research Centre in Ispra, Italy on 09/10 November 2006.

The workshop was a follow up of the 2005 workshop, which was initiated and chaired by Bernhard Dimmler, Würth Solar, Germany. It was co-organized by EPIA in the framework of the FP6 project "Creating Markets for RES" and the Renewable Energies Unit of IES.

Aim of the workshop

In the past 5 years, the yearly world market growth rate for Photovoltaics was an average of more than 40%, which makes it one of the fastest growing industries at present. Business analysts predict the market volume to increase to € 40 billion in 2010 and expect rising profit margins and lower prices for consumers at the same time.

Today PV is still dominated by wafer based Crystalline Silicon Technology as the "working horse" in the global market with more than 90% market share in 2005. The current silicon shortage has kept prices higher than anticipated from the learning curve experience and has widened the windows of opportunities for thin film solar modules. Current production capacity estimates for thin films vary between 1 GW and 2 GW in 2010, representing a 20% market share for these technologies. The different thin film technologies (TF) have the highest cost reduction potential of all PV technologies in middle and long term. Equally, competitive technologies are amorphous/microcrystalline Silicon, CdTe and the material family of $Cu(In,Ga)(Se,S)_2$ – thin films.

One of the main disadvantages of thin Film Technologies in comparison to Crystalline Silicon Technologies is still the not very advanced scientific database (at least for CdTe and CIS) and the missing maturity in production technology. In addition, the current testing standards were not developed for the new thin film modules on the market. To overcome these obstacles more efforts on further scientific R&D with respect to PV quality and stability on the one hand and on the establishment of professional and standardized production equipment under industrial circumstances bringing down manufacturing cost on the other hand are needed.

This participants of this years workshop came from Thin Film Photovoltaic companies already producing or just starting production, testing and certification laboratories and equipment manufacturers.

The key points of this workshop and the topics presented and discussed were:

- Preconditioning, Measurements and Testing of Thin Film Modules.
- Performance, calibration, traceability and energy rating.
- Module Sealing, Lamination.
- To find common future RTD topics that may result in RTD programs either in bi-lateral or multi lateral collaborations on a national or rather European level.

It is my strong believe that this workshop series will develop into a platform for future, fruitful exchange of ideas to accelerate the development and manufacturing capabilities of thin film technologies.

Ispra, December 2006

Arnulf Jäger-Waldau
Renewable Energies
European Commission – Joint Research Centre

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AGENDA

09 November 2006

14:00 – 14:10	**Welcome** Arnulf Jäger-Waldau and Heinz Ossenbrink, European Commission; DG JRC; Bernhard Dimmler, Würth Solar GmbH&Co. KG
14:10 – 14:20	**Introduction**, Bernhard Dimmler, Würth Solar GmbH&Co. KG
14:20 – 14:40	**TC 82 Activities on Thin Films** Heinz Ossenbrink, European Commission; DG JRC
14:40 – 16:15	Company presentations + experiences in module characterization and outdoor performance
16:15 – 16:45	**Coffee Break**
TOPIC 1:	**Preconditioning, Measurements and Testing of Thin Film Modules**
16:45 – 17:05	**Thin Film Module Testing**, Tony Sample, European Commission; DG JRC
17:05 – 17:25	**Preconditioning, Measurements and Testing of Thin Film Modules** Werner Hermann, TÜV Rheinland
17:25 – 17:45	**Solar Simmulator** Patrick Hofer-Noser, 3S Swiss Solar Systems
17:45 – 18:05	**Pulsed Solar Simulators and Measuring Systems for the Photovoltaic Industry** Detlev Berger, Berger Lichttechnik
18:05 – 18:15	Summary and Discussion
19:30	**Dinner**

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TOPIC 2:	**Performance, calibration, traceability and energy rating**
09:00 – 09:20	**Performance of Thin Film Modules** Keith Emery, National Renwable Energy Laboratory
09:20 – 09:40	**Energy Rating** Robert Kenny, European Commission; DG JRC
09:40 – 10:00	**Integrated Project "Performance"** Ewan Dunlop, European Commission; DG JRC
10:00 – 10:30	Discussion of Plans/Expectations of "IP-Performance" and of the Thin Film manufacturers
10:30 – 11:00	**Coffee Break**
TOPIC 3:	**Lamination**
11:00 – 11:15	**Economical Laminating -Today And Tomorrow** Herbert Ehlting, Meier Vakuumtechnik GmbH
11:15 – 11:30	**Laminators** Patrick Hofer-Noser, 3S Swiss Solar Systems
11:30 –12:30	Discussion on Module Sealing: Actual technique and future concepts
12:30 – 14:30	**Lunch**
14:30 –15:30	Discussion on possible synergies and collaboration in thin film photovoltaics and further workshops
15:30 – 16:00	***Conclusion and Close of the Workshop***

EXECUTIVE SUMMARY

SCOPE OF THE WORKSHOP

Introduction

The first International Workshop "Thin Films in the Photovoltaic Industry" in November 2005 found a big resonance and indicated the demand for a follow up. The 2nd International Workshop was even more in demand and was held at the European Commission's Joint Research Centre in Ispra, Italy on 09/10 November 2006. It was chaired by Bernhard Dimmler, Würth Solar together with Arnulf Jäger-Waldau, European Commission, DG JRC. The organization was supported by EPIA Brussels and hosted by JRC Ispra, Italy.
The results of this workshop are an important input to the Working Group «science, technology, industry and application» of the PV PLATFORM and - due to the main topic - to the Integrated Project PERFORMANCE recently started by the European Commission.

As Thin Film Industry is growing intensively with a number of new factories in the multi-ten-Megawatt capacity range with a big share especially in Europe, the need for targeted discussion fora like this workshop is increasing.

Background:

Photovoltaic solar electricity systems do have the potential to deliver electricity on a large scale at competitive costs. One of the main obstacles of PV today to serve as an important energy source is the high production costs for the PV module. Today PV is dominated by wafer based Crystalline Silicon Technology as the “working horse” in the global market (>90% market share in 2005). Thin films have the highest cost reduction potential of all PV technologies in mid and long term. The emerging materials are amorphous / microcrystalline Silicon and the compound polycrystalline semiconductors CdTe and CIS (CIS holds for the material family of Cu (In,Ga)$(Se,S)_2$). All of them are developing fast and are already in the status from small startups to large scale productions.

The disadvantage of thin Film Technologies in comparison to Crystalline Silicon Technologies is still the lack of fundamental material property data (at least for CdTe and CIS) and the missing maturity in production technology.

This workshop was aimed to increase the support to concentrate efforts on a common level.
The aim was to strengthen and increase the share and the role of thin film technologies in the worldwide PV market for the future.

TOPICS of the Workshop:

Beside the reduction of production costs the performance and reliability of the product over a long lifetime is of highest interest for the Thin Film manufacturers. Therefore, the topics for the 2006 workshop were the following:

Testing:
- Characterization of the thin film module by measuring the electric performance in simulated sun light compared to outdoor behaviour;
- Accelerated life time testing, type approval;

- Outdoor performance and energy rating.

Sealing:
- Lamination, state of the art;
- Cost reduction potential with innovative technologies and materials.

Further scientific R&D with respect to PV quality and stability and the establishment of professional and standardized characterisation equipment and methods under industrial circumstances is highly needed.
Finally the aim was to establish Thin Film Photovoltaics as a leading technology by minimizing investment and material costs and maximizing product quality and stability.

For this 2nd International Workshop "Thin Films in the Photovoltaic Industry" representatives from the emerging Thin Film Photovoltaic companies, which are already producing or just starting production, experts in the field of testing and certification as well as representatives from equipment manufacturers, in this case mainly of sun simulators and laminators, were invited on the European level.

The key points of this workshop and the topics to be presented and discussed were the following:

- To find and elaborate common needs of TF PV manufacturers in technology with the aim of standardization of quality control methods;
- To establish standardized test and performance certifications for the Thin Film products;
- To end up with a sustainable production and product;
- To find common future RTD topics that may result in RTD programs either in bi-lateral or multi lateral collaborations on a national or rather European level.

Expectations of the organizers

For the further support and to enable Thin Film Photovoltaics to become a leading technology in Photovoltaics in general the workshop was designed to find answers to the following questions:
- What is the real status of TF PV?
- What are the technological achievements?
- What are the bottlenecks to overcome?
- How can we create synergies between the companies (bilateral, multilateral) already active?
- How to bring these needs into common developments and into RTD programs? Etc.

INTRODUCTION

In 2005, the photovoltaic industry continued its impressive growth and delivered world-wide some 1,700 MWp of photovoltaic generators. In the past 5 years, the average annual world growth rate was above 40%, making the further increase of production facilities an attractive investment for industry. An investment report published in 2004 by Credit Lyonnais Security Asia forecasts that the photovoltaics sector has a realistic potential to expand from € 5.6 billion[1] in 2004 to € 24 billion in 2010, corresponding to 5.3 GWp in annual sales. In the meantime the bank analyst Mr. Rogol estimates that even 10 GW of annual sales with a € 40 billion turnover of the sector could be reached in 2010. In 2005 the employment figures in Photovoltaics for the European Union are estimated to be 40,000 to 42,000. These figures are estimated from the 30,000 jobs reported for Germany by the German Solar Industry Association and 6,300 for Spain reported in the IEA PVPS country report 2006.

About 90% of the current production uses wafer-based crystalline silicon technology. The top advantage of this technology is that complete production lines can be bought, installed and be up and producing within a relatively short time-frame. This predictable production start-up scenario constitutes a low-risk placement with high expectations for return on investments.

The current temporary shortage in silicon feedstock is triggered by the extremely high growth rates of the photovoltaics industry over the last years, which was not followed by the silicon producers. Three developments can be observed at the moment:

- Silicon producers have now reacted and are in the process of increasing their production capacities, which will ease the pressure on the supply side within the next two to three years. This indicates that they have recognised PV as a fully fledged industry that provides a stable business segment for the silicon industry, as opposed to being strongly dependent on the demand cycles of the microelectronics industry.
- PV companies accelerate the move to thinner silicon wafers and higher efficient solar cells in order to save on the silicon demand per Wp.
- New thin film manufacturers are entering the market to supply the growing demand for PV modules and significant expansions of production capacities. From 2004 to 2005, thin film shipments already increased by more than 50% from 60 MW to 94 MW and the new thin film factories currently under construction will increase the production capacity more than fivefold by 2008. If all thin film factories, which are currently in the planning stage are build, thin film photovoltaic could provide around 20% of the then 10 GW market in 2010.

Similar to learning curves in other technology areas, new products will enter the market, enabling further cost reduction. After years of research and technology development, thin film technology is now entering the industrial production. Equally, competitive technologies are amorphous Silicon, CdTe and CIS thin films. The growth of these technologies is accelerated by the positive development of the PV market as a whole and the temporary silicon wafer shortage. The expansions for the required scale-up to manufacturing units of 50 MWp annual capacity and more are under way and will soon join the wafer silicon devices technology in satisfying demand.

[1] Exchange rate used: $ 1.25 = € 1

If thin film should supply 20% of the photovoltaic devices by 2010, the growth of production capacities must be about double as high as the rest of the industry, assuming that total PV growth continues with more than 40% per year, as predicted by Mr. Rogol. By then, Silicon technology would deliver about 8,000 MWp per year, requiring 65,000 metric tons of Si-feedstock, about double today's entire world production capacities of semiconductor silicon (32,000 metric tons). Even the more conservative EPIA scenario of 27% growth would result in a silicon demand of 30,000 metric tons of Si-feedstock.

These scenarios show that in order to maintain such a high growth rate, different pathways have to be pursued at the same time:

- Drastic increase of solar grade silicon production capacities.
- Accelerated reduction of material consumption per silicon solar cell and Wp, e.g. higher efficiencies, thinner wafers, less wafering losses, etc.
- Accelerated introduction of thin film solar cell technologies into the market and capacity growth rates above the normal trend.

Further cost reduction will depend not only on the scale-up benefits, but also on the cost of the encapsulation system, if module efficiency remains limited to below 15%, stimulating strong demand for very low area-proportional costs.

SUMMARY OF PRESENTATIONS

Bernhard Dimmler, member of the steering committee of the EU PV Technology Platform and Chairperson of the meeting started the meeting's presentations with an overview of the key issues for Thin Film Photovoltaics to play a significant role in the Photovoltaics business. The current market situation is very favourable for Thin Film Photovoltaics and this fact is reflected in the fact, that not only new market players are choosing thin film photovoltaics as their technology to invest, but that an increasing number of established solar cell producers with previous focus on wafer based solar cells are broadening their solar cell production basis with thin film technologies.

The quintessence is that Thin Film Production capacities are rapidly increasing and by the end of the decade between 1,600 and 2,700 MW of production capacities for various thin film technologies could be realised.

The main shortcomings concerning thin film for photovoltaic applications are:

- Not sufficient knowledge about basic material properties.
- Limited maturity of production technology.
- Not sufficient knowledge how to measure the different thin film technologies with the same accuracy than crystalline silicon modules.
- Absence of suitable test standards for the different thin film technologies.

Some identified key points for thin film photovoltaics are:

- Reduction of energy pay-back-time of modules (from present 1.5 years to 0.5 years for central European climatic conditions).
- Ensure the availability of quality products with suitable energy conversion efficiencies.
- Ensure long term stability and lifetime of the modules.
- Development of suitable test procedures for the different kind of thin film technologies.
- Improvement of testing accuracy for thin film modules.

In an estimated world market of 10 GWp worldwide, thin film technology could reach a share of 20% (2,000 MWp) by 2010 and 25% (25 GWp) of a total of 100 GWp by 2020.

The main cost categories for thin film solar modules are:

- Materials: 45 – 55 % (½ of material costs for the active films and ½ for packaging (glass, laminate, junction box, etc.)
- Capital cost equipment: 20-25%
- Labour 10-15%
- Energy 5-8%

The next presentation was by Heinz Ossenbrink, who introduced the work of the International Electrotechnical Commission (IEC) Technical Committee 82 (TC 82) on Solar Photovoltaic Energy Systems, which is chaired by him. The focus of his presentation was the ongoing revision of the major IEC Document for thin films, IEC standard 61646 ed.1 (1996) for "Thin Film terrestrial photovoltaic modules – Design qualification and type approval". Another major IEC project is the new IEC standard 61853 "Power and energy rating of photovoltaic modules".

Then, each participant made a short presentation on the status of their work either with or without slides. All the different thin film technologies were present: amorphous/microcrystalline Silicon and the compound polycrystalline semiconductors CdTe and the material family of Cu $(In,Ga)(Se,S)_2$. The company presentations can be found in the Annex.

TOPIC 1:

PRECONDITIONING, MEASUREMENTS AND TESTING OF THIN FILM MODULES

Tony Sample from the European Commission's Joint Research Centre gave an overview on Thin-Film Module Testing. In the first part of the presentations he outlined the testing procedure and the relevant pass fail criteria for IEC 61646. The second part was devoted to specific Thin-Film issues and observed defects, which led to failures during the test.

The second presentation was given by Werner Herrmann from the Technischer Überwachungs-Verein (TÜV) Rheinland Immissionsschutz und Energiesysteme GmbH. He outlined the specific characteristics regarding the measurement and testing of thin film modules. He reported on the ongoing European activity in the PERFORFANCE IP, where in sub-project 1 the "Traceable performance measurements of PV devices" is addressed. With respect to thin film modules a "Round Robin Test" with commercially available Thin-Film modules is performed. Until now, harmonised measurement methods for Thin-Film modules are not available and the development of technology specific measurement procedures is required.

The second part of the session was devoted to the presentation of two test equipment manufacturers, 3S Swiss Solar Systems AG and Berger Lichttechnik. Both companies presented their products for thin film solar module testing.

TOPIC 2:

PERFORMACE, CALIBRATION, TRACABILITY AND ENERGY RATING

Keith Emery from the National Renewable Energy Laboratory (NREL) reported about their activities to determine the performance of Thin-Film Photovoltaic modules. The ultimate goal is to determine the "Current versus Voltage under Continuous Illumination at 25°C junction temperature and 1000 W/m^2 total irradiance according to the IEC Global Reference Spectrum". For thin films NREL's findings can be summarised as follows:

- A Variety of measurement artefacts for thin film devices are possible relating to sensitivity to pre-measurement conditions, bias rate, bias direction.
- Effects of short-term transient behaviour can be mitigated by light soaking near P_{max} for 5 min at 1-sun or longer.
- Metastable behaviour has been observed for CdTe, amorphous silicon, and CIGS.
- Calculation of the spectral matching can account for fill factor differences in multi-junction devices once bias rate issues common to pulsed simulators are mitigated.
- Uncertainty in I_{sc} and P_{max} are larger for thin-films than crystalline Si as evidenced by inter-comparison results.

Robert Kenny then reported about the experience with Energy rating for thin-Film modules at the European Commission's Joint Research Centre in Ispra. The following measurement issues were observed with respect to thin film modules:

- Light soaking is necessary to stabilise a-Si.
- During operation, the performance of a-Si does change (e.g. winter/summer) with combination of light soaking and thermal annealing processes.
- Light soaking of CIS has been found necessary immediately prior (order of minutes) to measurement on the simulator in order to achieve repeatable results.
- Underestimation of power, principally due to underestimation of FF of Cd-Te modules on pulsed simulator, as compared to outdoor measurements.

The current situation can be summarised as follows:

- c-Si
  - good match indoor/outdoor power surfaces
  - Good energy prediction
- CIS & a-Si
  - discrepancies indoor/outdoor
  => Poor energy prediction
  - Need to improve this situation

Ewan Dunlop presented the European Integrated Project PERFORM IP. The project has 28 partners and aims to improve the general understanding of

- PV device testing methods,
- PV module and system performance,
- PV module and system stability.

Following the project presentation the participants discussed about the necessary input of the thin-film community towards this project. The main topics were the improvement of measurement accuracy and comparability of measurement results from different laboratories for different thin film technologies.

TOPIC 3:

LAMINATION

The last session was devoted to the presentation of two lamination equipment manufacturers, Meier Vakuumtechnik GmbH and 3S Swiss Solar Systems AG. Both companies presented their products for thin film solar module lamination and developments for the future. So far the laminators are not designed for the particular needs of Thin Film devices. All participants agreed that more effort from manufactures and suppliers is needed to reduce the costs of the encapsulation.

ISSUES AND FUTURE RTD PROJECTS

After the presentation a general discussion followed. The main discussion was about the high uncertainties in the measurement results of thin film cells and modules. The following points were made:

- The measurement uncertainties for Thin Film module key parameters are still almost double that of wafer silicon based modules (± 4% vs. ± 2%). For a thin film market of roughly 100 MW in 2005 this is equivalent to € 4 million.
- Round Robin exercises revealed quite significant differences between the results of different European Test Labs. The following measures were suggested to improve this situation:
  - Identify permanent phenomena vs. reversible phenomena.
  - Remove transient effects from the measurements.
  - PERFORM IP is monitoring the used test equipment to identify sources of discrepancies. This includes test procedures used by different manufacturers.
  - As the module selection can have a significant influence on the results, "problematic" modules should be used.
    As an example the SOLAREX dual junction modules were quoted, which were either top or bottom cell limited.
    Another cited example was GOLDEN PHOTON, where modules exhibited up to 50% difference.
  - Expand the Round Robin to an International Test with one Procedure.
- The preconditioning of the different modules before the measurements is a crucial parameter. Each material combination and each manufacturing technology can exhibit different behaviour. This requires the knowledge of the specific behaviour of the module type.
- For the manufacturers the most critical issues are:
  - Tools for process control, i.e.
    - reference to calibration measurements,
    - linearity of devices.
  - Reliable in-house measurements to see at an early stage if something goes wrong.
  - Reliable measurements for output power to give guarantees to customers (third party confirmed, common protocol).

In general there was a common agreement, that more efforts to improve the reliability of measurements and to decrease the uncertainty are needed. All manufacturers were very much interested to see particularise of Thin Film modules reflected in the international standards.

ANNEX: WORKSHOP PRESENTATIONS

The Presentations are also available on the Web-Page of:

European Photovoltaic Industry Association

http://www.epia.org

Scientific Technical REFERENCE System on RENEWABLE ENERGY and ENERGY END-USE EFFICIENCY

http://streference.jrc.cec.eu.int

Thin Films in the PV Sector
2nd Int. PV Workshop on thin Films

Bernhard Dimmler
Würth Solar GmbH & Co. KG

Schwäbisch Hall
bernhard.dimmler@we-online.de

www.wuerth-solar.de

2nd Int. PV Workshop on thin Films

Workshop Topics:

Topic 1:
Preconditioning, Measurements and Testing of Thin Film Modules

Topic 2:
Performance, calibration, traceability and energy rating

Topic 3:
Module Sealing, Lamination

Thin Films for energy production with PV

* PV today is dominated by wafer based Crystalline Silicon Technology

* Thin films PV have the highest cost reduction potential of all PV technologies in middle and long term.

The emerging materials are: - amorphous / microcrystalline Silicon
- CadmiumTelluride (CdTe)
- CIS: $Cu(In,Ga)(Se,S)_2$

All are starting with several large volume factories with very good prospects to reduce costs of PV modules
Lacks of thin Film Technologies:
* Material knowledge (at least for CdTe and CIS) still low
* maturity of production technology still low

Source: survey of
Jäger-Waldau Nov.2005
+ author + NREL

Thin Film activities in industry worldwide
(most important and known)

Japan

Canon: research: a-Si/a-SiGe/a-SiGe; a-Si/µ-Si/ µ-Si
Fuji Electric:flexible a-Si, production announced for 2006
Honda: CIGS research (pilot plant), production announced for 2007
Kaneka Solartech: production a-Si and "Hybrid PV Modules"
Matsushita Ecology Systems: research: CIGS
Mitsubishi Heavy Industries: production a-Si solar cell
SANYO: production: a-Si; research: a-Si/µ-Si
SHARP: production announced: a-Si/µ-Si
Shinko Electric Industries Co., Ltd.: research: CuInS2
Showa Shell Sekiyu: CIGS production announced for 2007

USA

Day Star: research: CIGS, production announced
Energy Photovoltaics, Inc. (EPV): research: a-Si and CIGS)
First Solar: production CdTe
Global Solar: production: CIGS on flexible
Iowa Thin Film Technologies: research and pilot: a-Si
Nanosolar: announcement of 430 MW/a CIGS
UNISUN: research: CIGS
UnitedSolarOvonic: production: a-Si, research a-Si/µ-Si
Miasole:research, soon pilot production CIGS
ISET: F&E CIGS

Europe

Aleo/ife/johanna: production with 20 MW/a announced for 2007
Akzo Nobel: research: a-Si
ANTEC Solar: production: CdTe
Q-cells: production 20 MW/a announced: a-Si
CIS Solartechnik GmbH: research: CIS, production planned.
Ersol: production 20 MW/a announcd: a-Si
First Solar: production CdTe 2007
Free Energy Europe: production: a-Si
Intersolar UK: production: a-Si
Scheuten Solar: research/pilot CIGS
Schott-Solar GmbH Phototronics (PST): production: a-Si
Shell Solar (Munich, Germany): research CIGS
production expected soon together with SGG
Solar Cells (Croatia): production: a-Si
Solarion GmbH: development and pilot: flexible CIGS
Solibro AB (Sweden): CIGS research
Sulfurcell Solartechnik GmbH: pilot: CuInS2
UNAXIS Solar: research a-Si/µ-Si-hybrid and production equipment
VHF Technologies: pilot: a-Si (flexible)
Würth Solar GmbH: production: CIGS

red … CIS
weak blue … a-Si
dark blue … CdTe

Thin Film PV is taking off

“Thin Film production capacities are increasing rapidly“

due to:

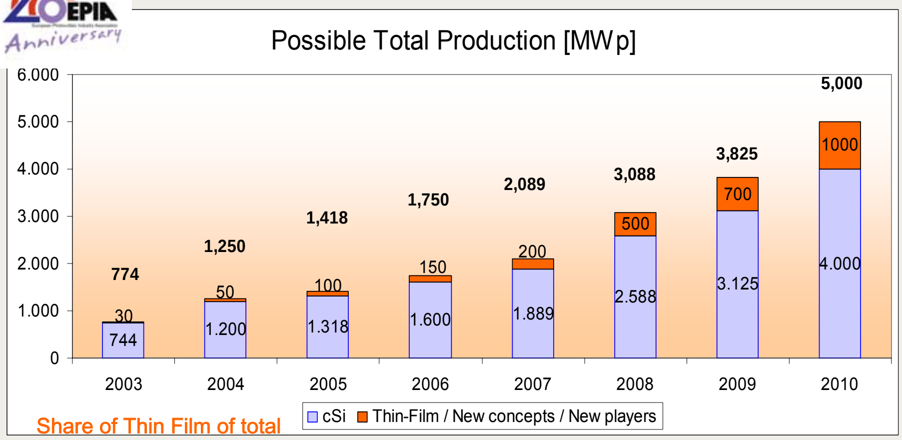
- After 25 years of development Thin Films have gained enough technological maturity and proven quality with calculable risk.
- performance and life time expectations proven.
- High cost reduction potential, just starting learning curve

And accelerated by
PV market volume increase and Silicon shortage

Module Production

c-Si, Thin Film as estimated by end of 2005

Source:



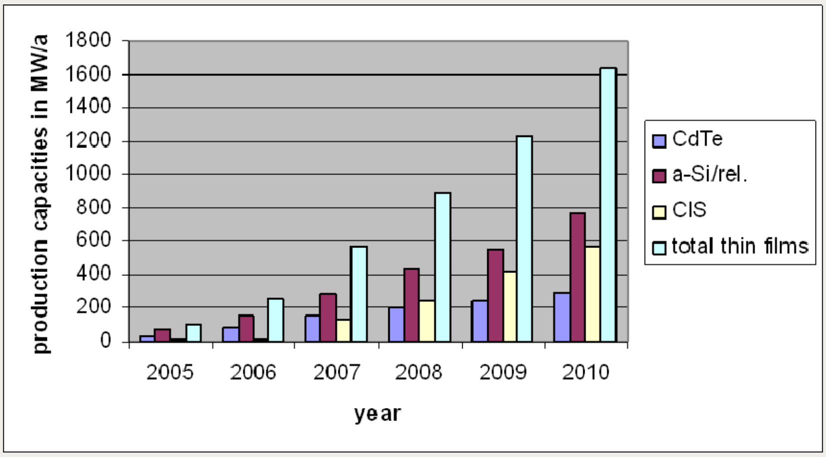
Share of Thin Film of total

3.8 %	4.0 %	7.1 %	8.6 %	9.6 %	16.2 %	18.3 %	20 %

Estimation: 2020 thin films 7.5 GW (=22%) of total 34 GW,
2030 thin films 133 GW (= 28.6% = new concepts) of total 380 GW

Expected Evolution of Thin Film Module Production Capacities

counting existing, announced and expected* productions worldwide



•expected: slight or no increase after first announced capacities including assessment of technological maturity

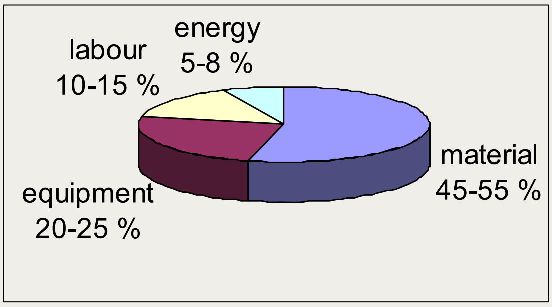
What makes the customer to Buy a Thin Film Module instead of c-Silicon

1. Price per Watt
2. Quality / conversion efficiency
3. Long term Stability
4. Reliability
5. Money to earn: kilowatt-hours / capital invested (kW installed) energy rating

Confidentiality to the product/manufacturer to fulfill the promised advantages

By standardized and calibrated measurement procedures

1. Price per Watt
Manufacturing costs: Cost shares



Cost can vary about 10% relatively for each cost category for the various materials

~ ½ of material costs for films, ½ for packaging (glass, laminate, junction box, etc.)

Main reduction potential by reduction of material cost:
i.e. for films material: material yield and purity, film thickness
for packaging: new concepts with foil substrates and diffusion barriers

International Electrotechnical Commission
Technical Committee 82
Solar Photovoltaic Energy Systems

Standards on Thin Film technology

Dr. H. Ossenbrink
Chairman TC82

2nd International PV Industry Workshop on
Thin Films, Ispra, 2006-11-09

St. Louis Declaration, 1904

"That steps should be taken to secure the co-operation of the technical Societies of the world by the appointment of a representative Commission to consider the question of the standardization of the Nomenclature and Ratings of Electrical Apparatus and Machinery."

Statutes drawn up London 1906
Lord Kelvin, 1st President

25 Years TC82

Established 1981,

1st Chairman M. LeClerque (LCIE, FR)

- WG 1, Glossary
- WG 2, Modules, non-concentrating
- WG 3, Systems
- WG 6, Balance-of-System Components
- WG 7, Concentrator Modules

~75 Standards Published (3 per year)

TC82 and the last 25 PV years

1981:	2006:	
18 MW_p	1700 MW_p	(31%/yr)
30 MWp Total	5000 MW_p Total	
25 $\$_{2002}$ / W_p	5 $\$_{2002}$/ W_p	(-6.5 %/yr)

2nd International PV Industry Workshop on
Thin Films, Ispra, 2006-11-09

TC82 and the PV Future

2010: 10 GWp / yr (40%/yr)
2020: 100 GWp / yr (26%/yr)

Major Markets:
- Professional Grid for Peak Demand
- Rural Electrification

2nd International PV Industry Workshop on
Thin Films, Ispra, 2006-11-09

Anticipate Needs

Lifetime Energy Production

How many years to pay back investment?

Reliable Electricity Delivery in Rural Regions

How to Design Complex Hybrids?

Reduce Costs of Building Integration

How to avoid the trap of labour costs?

Meet Environmental Standards

How to meet the expectations for clean energy?

170'000t in 2026?

Lifetime Energy Production

Peak Power	(± 2%)	*Calibration*	*[W_p]*
Yearly Yield	(± 10%)	*Energy Rating*	*[$Wh/W_p/y$]*
Equivalent Lifetime	**(± 50%)**	***EoL testing?***	***[Wh/W/y]***

Global Market Value of Calibration alone:

±2% equivalent to ±500 Mio$ revenue in 2010, when 10 GW are produced

Trade Barriers

Global Markets:

– Wafers, Cells, Modules, BOS, Systems

Major Technical Barriers Do Exist:

Inverters (2006 sales: ~ 600 Mio$)

– Grid interface

– Safety

– EMC, Recycling/ Disposal, Env.friendly Mat.

– Project Management / Design Quality

Thin Film Standards

Major Document:

– **IEC 61646** ed.1 (1996)
Thin-Film terrestrial photovoltaic (PV) modules – Design qualification and type approval

Other existing revisions take thin-films into account, as far as possible (904-X series)

2^{nd} Revision of IEC 61646

- A Committee Draft for Vote (CDV) is in circulation to the 23+13 Members since 2006-06-30
- Deadline for Voting: 2006-12-01
- Parallel Voting at CENELEC

Changes from 1^{st} Edition (1)

1. The major change is in the **pass/fail criteria**. It no longer relies on meeting a plus/minus criteria before and after each test, but rather on meeting the **rated power after all of the tests** have been completed and the modules have been light soaked. This was done to **eliminate** the technology specific **preconditioning** necessary to accurately measure the changes caused by the test. (Some modules lose power in light while others lose power during dark heat.)

2. Changed “Scope and object” to “Scope and Purpose”.

Changes from 1st Edition (2)

3. Updated Normative References
4. Added a definition of “minimum value of maximum output power”.
5. Modified the wording in Major visual defects to allow some bending and misalignment without failure.
6. Added requirements to the report from ISO 17025.
7. Removed the “Twist Test” as we did from 61215, since no one has ever failed this test.
8. Made the pass/fail criteria for insulation resistance and wet leakage current dependent on the module area.
9. Added the temperature coefficient of power (δ) to the required measurements.

Changes from 1st Edition (3)

10. Modified temperature coefficient section to allow for measurements under natural sunlight or a solar simulator.
11. Deleted reference plate method from NOCT.
12. Added apparatus sections to test procedures.
13. Rewrote the Hot Spot Test.
14. Eliminated edge dip method from Wet Leakage Current Test.
15. Changed Mechanical Load test to 3 cycles to be consistent with other standards.
16. Added by-pass diode thermal test.

The Other Major Project

Project IEC 61853

Power and energy rating of photovoltaic (PV) modules

- IEC 61853 *-1 Power Rating.*
- IEC 61853 *-2 Test Methods*
- IEC 61853 *-3 Energy Rating*

Status: Committee Draft will be circulated for voting as "New Work Item Proposal" (NWIP)

I Wish You a Successful Workshop

calyxo

Company Presentation

09-Nov-2006 Ispra, 2^{ed} International PV Industry Workshop on Thin Films

calyxo

Calyxo at a glance

Employees: 9

Shareholder: 100% Q-Cells AG

Management: Meendert Buurman (CFO), Dr. Ralf Wendt (CTO)

Product: Thin Film Glass-Glass PV Module 60 cm x 120 cm

Launch of product: 2007

Location: Thalheim, Germany

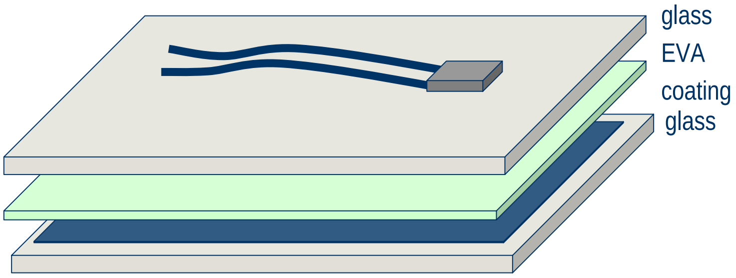
calyxo

History

Aug. 2005	Foundation of Calyxo GmbH Task: to build a R&D line for sample production of thin film modules
Sep. 2005	ordering of key equipment completed
Mai. 2006	building is ready for equipment move in
Jun. 2006	starting of process development
Oct. 2006	first results on key processes and efficiency / decision on further investment to accelerate product development

calyxo

Technology and Product



Start of product testing Q2 2007!

Thank You!

09-Nov-2006 Ispra, 2^{ed} International PV Industry Workshop on Thin Films

Accelerated Durability Testing

Author
Dr. Axel Straub,
Process Specialist
for everyone at CSG Solar

2nd Thin Films in Photovoltaic Industry workshop,
JRC/IES, Ispra, Italy

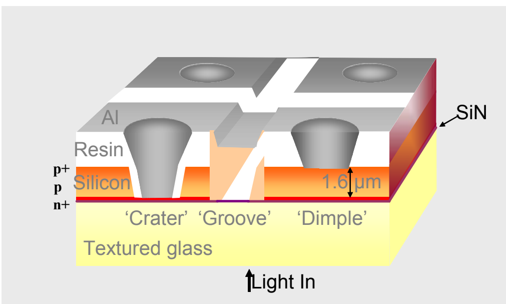
Language
Australian English

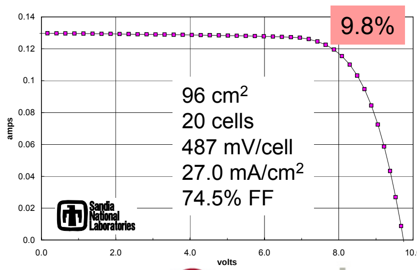
Presented 9./10. November 2006

csgsolar
taking the next step

A Brief History of CSG

- Developed in Australia since 1995
  - PECVD, SPC, RTA, H (numerous patents)
  - Best confirmed minimodule efficiency: 9.8%
  - Best measured designated-area efficiency: 10.0%
- CSG Solar AG formed in June 2004
  - Factory constructed in Thalheim, Germany
  - Best confirmed total-area module efficiency: 6.1% (84 watts)
  - Best measured designated-area efficiency: 7.3% (94 watts)



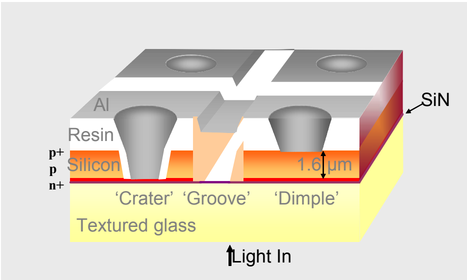


csgsolar

Crystalline Silicon on Glass

- 1.38-m^2 framed modules with a superstrate configuration.

- Technology:
  3 mm **Borofloat glass** → glass texturing (**Sol gel** + small **glass beads**)
  → **SiN** and **a-Si** deposition → crystallisation of the a-Si film
  → high temperature annealing → hydrogenation → cell separation → apply **resin** film
  → structuring (contact openings) → sputter **Al** → laser structuring of Al film
  → edge isolation → tabbing (tin free solder)
  → lamination (**EVA** and **Tedlar**) → **junction boxes**
  → framing (anodised **Al frames** with 2 crossbar)



csgsolar

Current Production Status

- **CSG-1 + CSG-2** (nominal throughput of 20 panels per hour)
  - Initial factory-scale demonstration of the CSG technology
  - First 'functional' panels produced in April 2006
  - Production stepped up to 24 hour operation, 4 days per week (2 shifts)
  - Most of the CSG-2 equipment installed
  - CSG-2 laser and ink-jet not yet installed

- Expansion of the factory to its full capacity to **generate positive cash flow**

- Establish a **baseline**
  - Sustainable process (yield, throughput and costs).
  - Produce the first module which satisfies all necessary requirements (power, aesthetics, durability)
  - Start certification process

- **Ramp up** throughput

csgsolar

How Do You Control Durability?

How do you control durability in a fast changing environment?

- Fast changing environment is **not the exception** but the norm during process establishment, ramp up and fast expansion of production capacity
- Very important for **product release**

→ **Confidence** in the durability of the 'base-line material' (combined cycle testing of pilot line modules)

→ **Process control** / **In-line characterisation** (not readily available for thin film production lines)

→ **Continuous testing** to identify problems

→ Develop **tailored tests** (if possible)

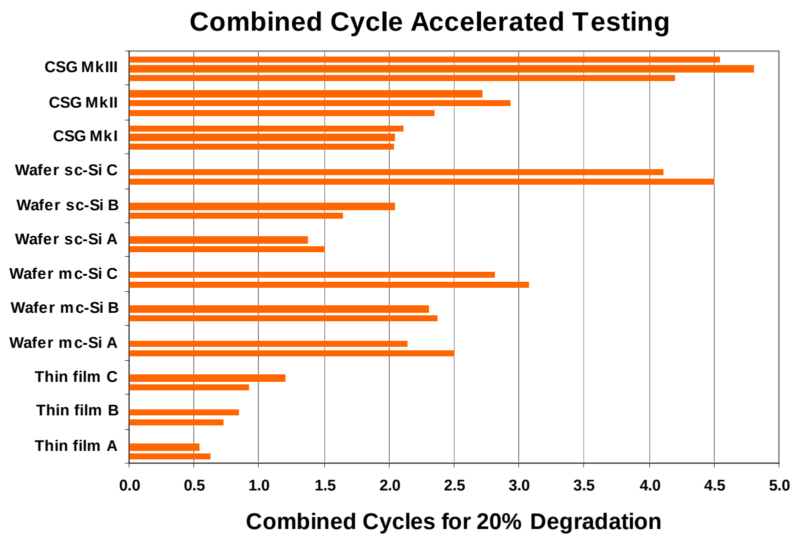
→ Strong need for even **faster accelerated durability tests**

Combined Cycle Testing

A 'Combined Cycle' exposes the same module to
200 Temperature Cycles then **10 Humidity Freeze cycles** then
1000 hours Damp Heat.

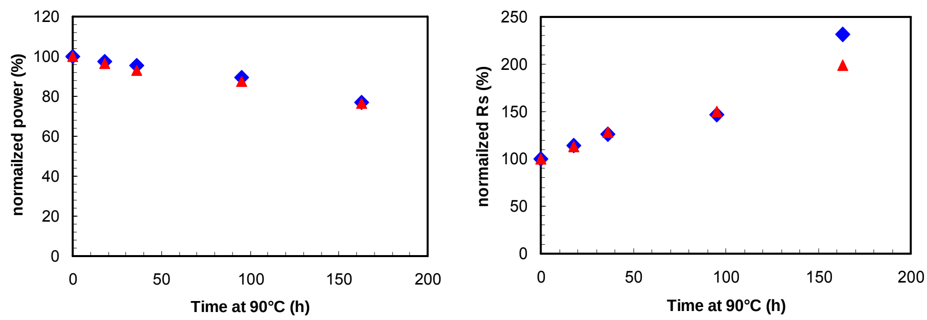
- Individual tests are well established in the PV industry
- Order is based on the sequence in IEC-68-1
- More confidence that CSG modules will survive the required warranty period
- Test sequence has weeded out several process changes that appeared good when tested to only one of the tests
- Results of 'faster' cycles have been less consistent and believable than those of combined cycle testing

Comparison with other Technologies



csgsolar

Case Study – Contact Contamination I



- Power degradation caused by an **increase in series resistance**
- Light IV tester measures at 4 different light intensities simultaneously
  - → **Parameterization of IV-curve**
    (series resistance, shunt resistance, photo shunt, dark saturation currents)
- Initially observed during **dry heat temperature cycling** and **outdoor tests**
- Dry heat at 90°C was more effective than temperature cycling
  - → **Faster response allows for better troubleshooting**

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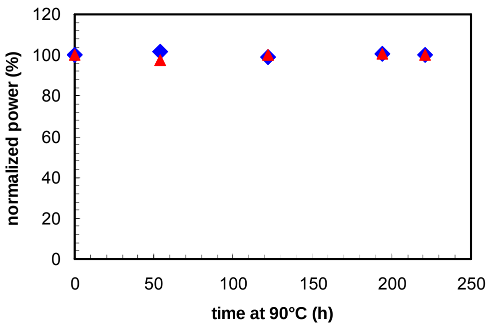
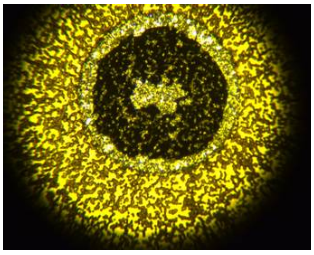
Case Study – Contact Contamination II





- Contamination in the contact openings
- Insufficient DI water rinse after contact formation
- Increasing the rinse resulted in a stable module power

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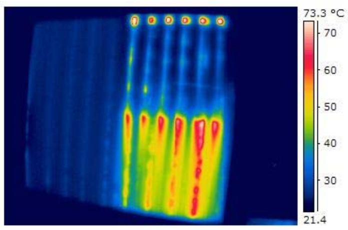
Page 10

Key Results on CSG Modules

- Pilot-line CSG modules are durable:
  - Comparable to high quality wafer c-Si modules.
  - More than 4 combined cycles with less than 20% degradation
  - Lamination not needed for durability
- In-line process control
  for thin-film production lines



- Good module characterisation is essential
- Continuous testing to identify problems
  (outdoor and temperature cycling)
- Tailored tests are useful for troubleshooting
- Faster accelerated durability tests would be desirable
  - Rapid temperature cycling (-20°C to +70°C), plus various combinations with damp heat and humid freeze were tested with little success

csgsolar

oerlikon
balzers coating

solar

Introduction to Oerlikon Solar
&
Discussion

Johannes Meier

CTO Oerlikon Solar

Oerlikon Solar-Lab SA, Puits-Godet 12a, CH-2000 Neuchâtel, Switzerland

OC Oerlikon AG, LI-9496 Balzers, Liechtenstein

oerlikon
balzers coating

solar

Rebranding

Unaxis Semiconductor
Unaxis Solar
Unaxis Optics
Leybold Vacuum
ESEC
Contaves Space
etc…..

oerlikon

oerlikon balzers coating

oerlikon leybold vacuum

oerlikon esec semiconductor

oerlikon components

In future none of these traditional brands will appear independently or without the umbrella brand, in order to display our joint unity and size.

After 1st of September 2006 !

oerlikon
balzers coating

solar

Roots: IMT research from Prof. Arvind Shah

Institut de Microtechnique, Université de Neuchâtel

– Start PV Lab at IMT by Prof. Arvind Shah	1985
– VHF PECVD deposition technique	1986
– Micromorph solar cell (Tandem amorphous/microcrystalline silicon)	1994
– Intermediate reflector in tandem cells	1996
– LPCVD ZnO development	1997
– CTI project: CRPP/IMT with Oerlikon (single chamber process in KAI reactors)	2000-2003

– Oerlikon (former Unaxis) decided to enter in PV 2003

To be the leading supplier of production systems and processes for thin film silicon solar modules

oerlikon
balzers coating

solar

Oerlikon Solar-Lab in Neuchâtel (R&D)

Why Neuchâtel?
Close to IMT and CRPP/EPFL

Goal: Process Transfer from Lab to Production

Oerlikon Solar in Neuchâtel
Puits-Godet 12a:
complete R&D Lab (clean/grey room)

oerlikon
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solar

Oerlikon Solar

Truebbach (east-CH)

Development and Engineering in

- KAI 1200 & TCO 1200
- System integration
- Process integration

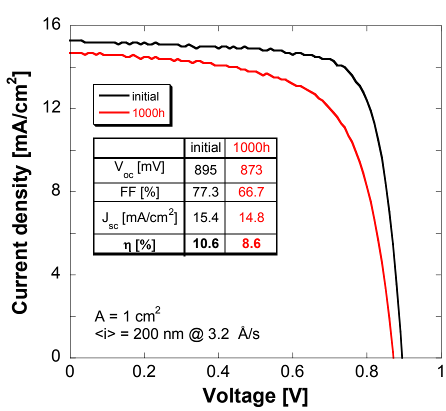
Product Mgmt & Sales in TBB

Solar team: > 100 people today

oerlikon
balzers coating

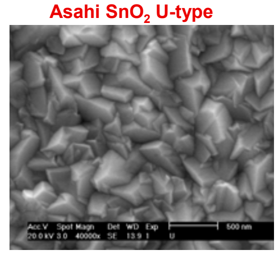
solar

Best a-Si:H p-i-n test cells on Asahi (KAI-M)



	initial	1000h
V_{oc} [mV]	895	873
FF [%]	77.3	66.7
J_{sc} [mA/cm^2]	15.4	14.8
η [%]	**10.6**	**8.6**

Asahi SnO_2 U-type



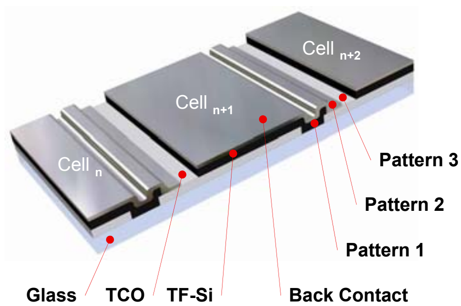
i-layer = 0.20 μm

η = 10.6 %> 8.6 %

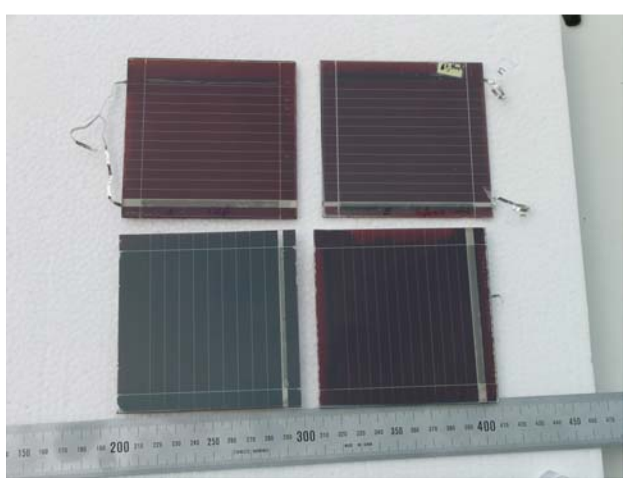
$\Delta\eta/\eta$ ~ 19 %

in **single-chamber batch process**!

Monolithic series interconnection



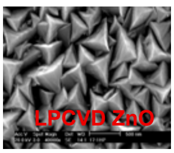
From test cells to 10x10 cm² modules

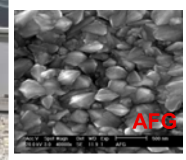


œrlikon
balzers coating

solar

1.25x1.1 m^2 a-Si:H p-i-n modules on LPCVD ZnO and AFG SnO_2





industrial size 1.4 m^2 modules

œrlikon
balzers coating

solar

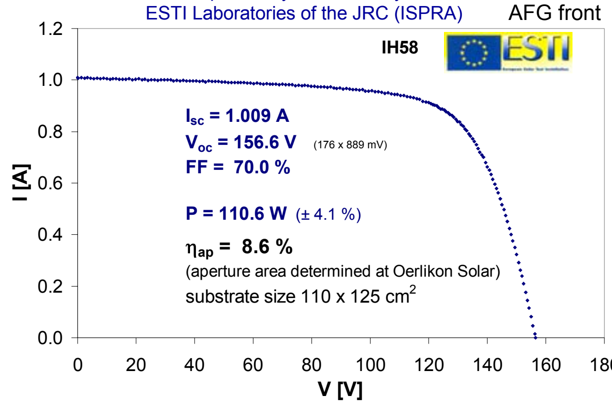
1.1x1.25 m^2 a-Si:H pin modules on AFG SnO_2 : 110.6 W

Initial

industrial size 1.4 m^2 modules

Independently measured by the ESTI Laboratories of the JRC (ISPRA)

AFG front

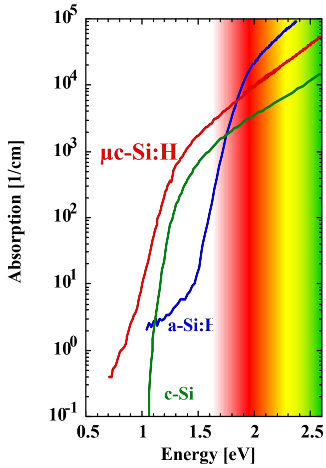


i-layer = 0.28 μm @ 3.4 A/s

oerlikon balzers coating **solar**

PECVD technique allows for different absorber materials:

a-Si:H, a-SiGe:H and μc-Si:H



Different band gaps

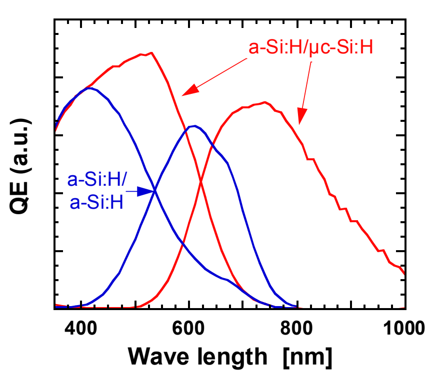
Different types of thin film solar cells

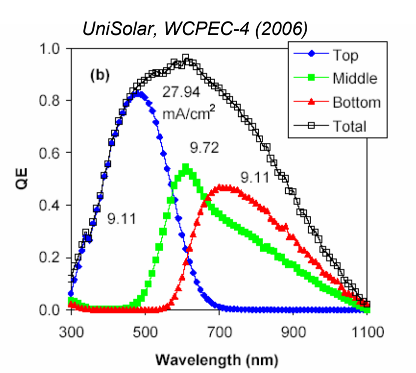
Especially,

tandem and triple-junctions !

oerlikon balzers coating **solar**

Examples of tandems & triples





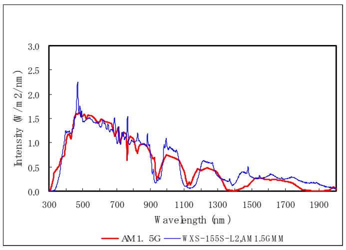
a-Si:H / μc-Si:H / μc-Si:H

Different spectral sensitivity of sub-cells

For Discussion

from test cells (1 cm^2) to
large-area thin film Si module characterisation

- Test cells
  stationary simulators (AM1.5)



OK for tandems,
works under good AM1.5 spectrums

However,

- Indoor large-area characterisation (>1m^2): Flasher

single-junction OK,

but tandems or even triples?

**Is at the moment outdoor
the only solution?**

PHOTOVOLTAIC INSTITUTE BERLIN

Photovoltaik-Institut Berlin AG i.G.
(PI-Berlin)

Solar module technology
Testing | Consulting | Research

Company overview, confidential

Company overview
PHOTOVOLTAIC INSTITUTE BERLIN

Company name:	PI Photovoltaik-Institut Berlin AG i.G., founded 12.10.2006
Invest:	1,2 Mio € (80% in Equipment)
Company site:	c/o TU Berlin, Einsteinufer 25, D-10587 Berlin, Germany
Phone/Fax:	+49 30 3142 5977 / +49 30 3142 6617
Founders:	Nine PV specialist based in Berlin
Active Team:	four senior consultants in solar module technology
Contact:	arp@pi-berlin.com, grunow@pi-berlin.com, lehmann@pi-berlin.com, krauter@pi-berlin.com

Actual company activities:

• **Founding of "PI-Berlin AG"**	**12th October 2006**
• **Co-operation contract with the Technical University Berlin**	**November 2006**
• **Inauguration Test Laboratory**	**1st Quarter 2007**
• **Start own R&D projects**	**End 2007**

People

PHOTOVOLTAIC INSTITUTE BERLIN

Managing Board and active staff: Four Berlin PV module specialists

Dr.-Ing. **Jürgen Arp**, Business Administration/Mechanical engineering
Career: Sputnik Engineering Inverters, Abastrial Solarconsulting Berlin

Dr. rer. nat. **Paul Grunow**, Physicist
Career : Solon, Q-Cells

Prof. Dr.-Ing. **Stefan Krauter**, Electrical Engineer
Career : Professor at TU Berlin and UFRJ/UECE Brasil, RioSolar Ltd, Director LAREF(fair)/RIO 06 (conference) Brasil

Dipl.-Ing. **Sven Lehmann**, Electrical Engineer
Career : Energiebiss, Solon, SolarExperts Berlin

Equipment (available 2007)

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Test laboratory equipment
- Class A Flasher and Spectral response set-up for precision measurements
- Climatic chambers 2m x 3m x 2m (heat-damp, thermal cycling, humidity freeze)
- Continuous light simulator class C (Hot spot, degradation)
- Outdoor measurement site
- UV test
- Wet leakage isolation test, Dielectrimeter
- Mechanical testing (load, breakage, twist, hail, scratch)
- Bypass Diode reverse load test
- Inflamation test stage

R&D equipment
- Laminator
- IR-camera for failure detection
- Soldering lab
- Characterization (tbd)

Fig.1: Out-door measurment set-up in Berlin

Threefold Business Concept

PHOTOVOLTAIC INSTITUTE BERLIN

Testing of Solar Modules

- STC power (Class A simulator)
- Energy yield estimate (temperature, low light performance, spectral response)
- Reliability (Extended test sequences to the IEC 61215/IEC 61646)

Consulting in Solar Module Technology

- Product and market analysis
- Appraisals, failure analysis
- Assessment of innovative product concepts
- Training (Product manager, Sales Manager, Developer)

Research & Development in Module technology

- New materials and concepts for cost reduction in thin film lamination
- Advanced thick film soldering
- Quality assurance strategies in module production

Customers and Market needs

PHOTOVOLTAIC INSTITUTE BERLIN

- Thick film **Cell producers** without module production
- **Thin film** manufacturers
- Wholesale **dealers**
- **Module** producers
- Product developper and/or **Investors**

The strong market growth needs more **independent testing facilities.**

The PV module technology needs more **R&D to decrease lamination costs**, especially for the emerging thin film technologies and as well for new wafer-based concepts.

PI-Berlin vs. other R&D institutions/suppliers

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- Fraunhofer **ISE Freiburg**: Conventional thick film modules
- **GP Solar**: thick film cell technology, modules yet
- **ISFH** Hameln: starting module R&D
- **ISET** Kassel: PV system technology
- **ZAE:** module R&D (planned)
- **HMI** Berlin, ZSW, IPV and others: Research on Thin Films, very little on modules

→ PI-Berlin focuses on thin film module technology and new module concepts in thick film technology

Remarks: **ECN** Netherlands and **NREL** USA are working on module technology on the international level, but their is a lack in Germany

Facility management provider or turn-key **equipment suppliers** are considered as potential partners, where PI-Berlin is servicing in product development.

PI Photovoltaik-Institut Berlin AG i.G. for Module Technology: Testing | Consulting | Research 7

Services (planed for Q1 2007)

PHOTOVOLTAIC INSTITUTE BERLIN

Laboratory package

includes:

- on-site office for a product developer/manager of the customer
- assistance from Senior consultant 2 days/month
- yearly product workshop at the customer
- usage of the three climate chambers for modules up to 3x2m²
- measurements (5 module/month indoor, 1 day/month outdoor)
- 2 days/month for usage of other testing equipment relevant for IEC and UL certification
- master and PhD thesis on fundamental problems
- access to the PI-Berlin's data base
- assessment of new product concepts

Consultant per day

Senior Consultant per day

PI Photovoltaik-Institut Berlin AG i.G. for Module Technology: Testing | Consulting | Research 8

Pre-testing services (planed for Q1 2007)

PHOTOVOLTAIC INSTITUTE BERLIN

Precision STC power measurement 1 module up to 2 m x 1,4 m < ±3
Standard STC power measurement 1 module up to 2 m x 1,4 m < ±3%
Any additional measurement up to 5 modules of the same type
Any additional measurement up to 50 modules of the same type

Isolation test Wet Leakage

Spectral Sensitivity isolated cell in the module
Cross link test > 5g EVA
Mechanical load tests (heavy load test, hail)*
UV Test
Temperature Cycling, Damp-Heat, Humidity Freeze

= Pre-testing for IEC 61215/61730 und IEC 61646

PI Photovoltaik-Institut Berlin AG i.G. for Module Technology: Testing | Consulting | Research 9

PHOTOVOLTAIC INSTITUTE BERLIN

Thank you

PI Photovoltaik-Institut Berlin AG i.G. for Module Technology: Testing | Consulting | Research 10

Production of Micromorph PV Modules at Q-Cells

Q-Cells

Johan Wennerberg

Brilliant 234. GmbH

2nd International Thin Films in Photovoltaic Industry Workshop, ISPRA, 9-10 Nov 2006

Q.CELLS

Q-Cells at a glance

Q.CELLS

Core Business

- World's second largest cell producer
- Forecast 2006: Production 255 MW_p
  Sales EUR 525 million
- Strategy: Growth and cost reduction
- Strong focus on R&D/new technologies
- New cell concepts and thin film modules

New Technologies

EverQ GmbH
- String Ribbon technology
- Q-Cells share: 33%

CSG Solar AG
- Thin-film technology: Crystalline Silicon on Glass
- Q-Cells share: 23%

Brilliant 234. GmbH
- Micromorph silicon thin-film technology
- Q-Cells share: 100%

VHF-Technologies SA
- a-Si roll-to-roll on film ("flexcell")
- Q-Cells share: 15 to 51%

Calyxo GmbH
- Thin-film technology
- Q-Cells share: 100%

NewCo GmbH
- Thin-film technology under consideration

Leader in core business with future-oriented new technology base

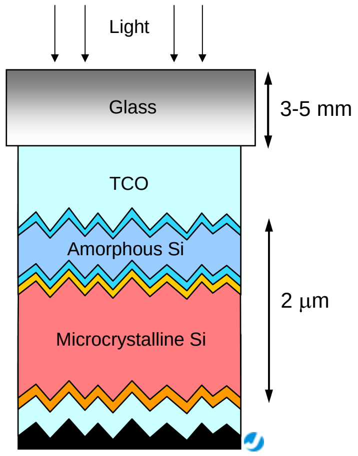
2nd International Thin Films in Photovoltaic Industry Workshop, ISPRA, 9-10 Nov 2006

Q.CELLS

Micromorph Si thin film technology

- Tandem concept
- pin/pin structure
- Superstrate configuration

State-of-the-art efficiency
- small area cells: 13%
- mini modules: 12%

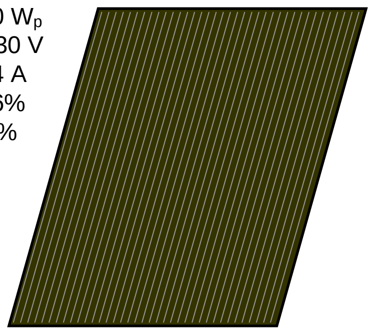


Preliminary product design

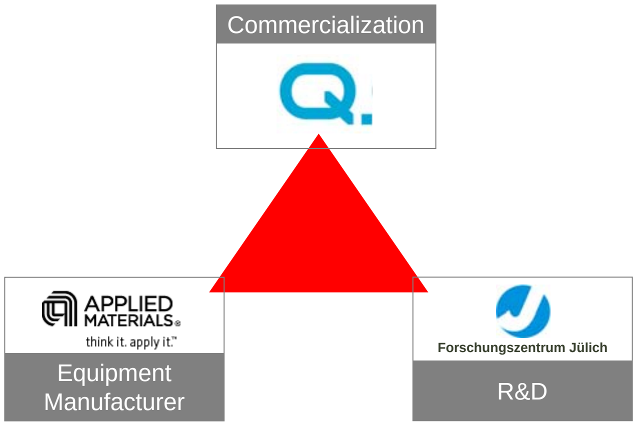
Module size: 1.4 m^2
(Substrate: 1508x932x4 mm)

Glass/Tedlar *or* Glass/Glass

$P = 120\ W_p$
$V_{oc} = 130\ V$
$I_{sc} = 1.4\ A$
FF = 66%
$\eta = 8.5\%$



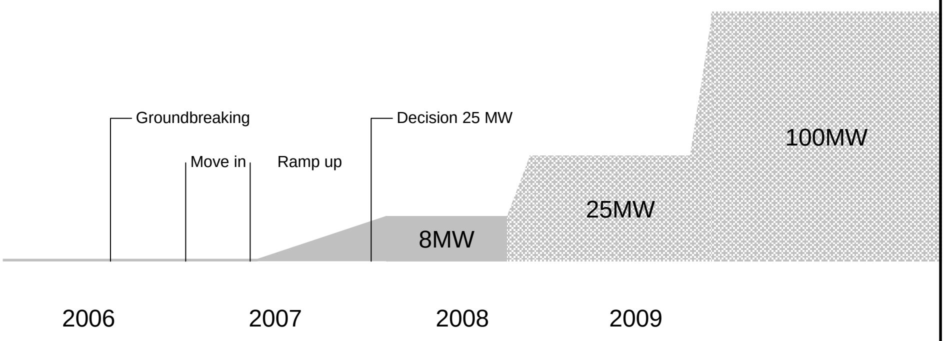
Based on strategic partnership



Q.CELLS

Timeplan

- Initial capacity 8 MW
- Quick decision for 25 MW
- Roll-Out 100 MW



Q.CELLS

Brilliant 234. building site (6 Nov 2006)

Phase 1: 8 MW, 4.000 m^2
Phase 2: 25 MW, 7.000 m^2
Phase 3: 100 MW, 21.000 m^2

12 hectare land available for further expansion

Issues for discussion

- **Flash tester**
  - Spectrum
  - Uniformity
  - Illumination time
- **Stability**
  - Edge sealing
  - Barrier
  - Encapsulant
- **Cost reduction**
  - Encapsulation

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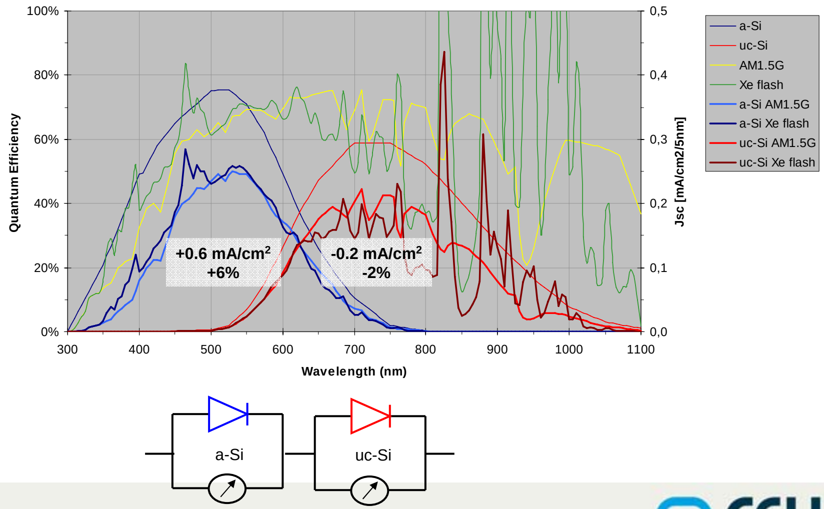
Q.CELLS

Flash tester - Spectrum



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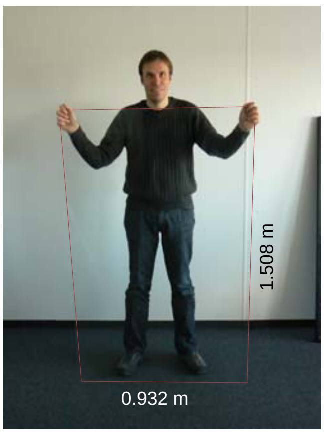
Uniformity



Module size: 1.4 m²
(Substrate: 1508x932x4 mm)

Glass/Tedlar *or* Glass/Glass

$P = 120\ W_p$
$V_{oc} = 130\ V$
$I_{sc} = 1.4\ A$
$FF = 66\%$
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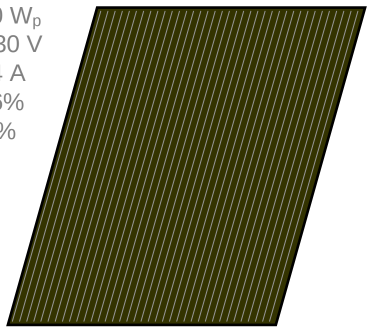

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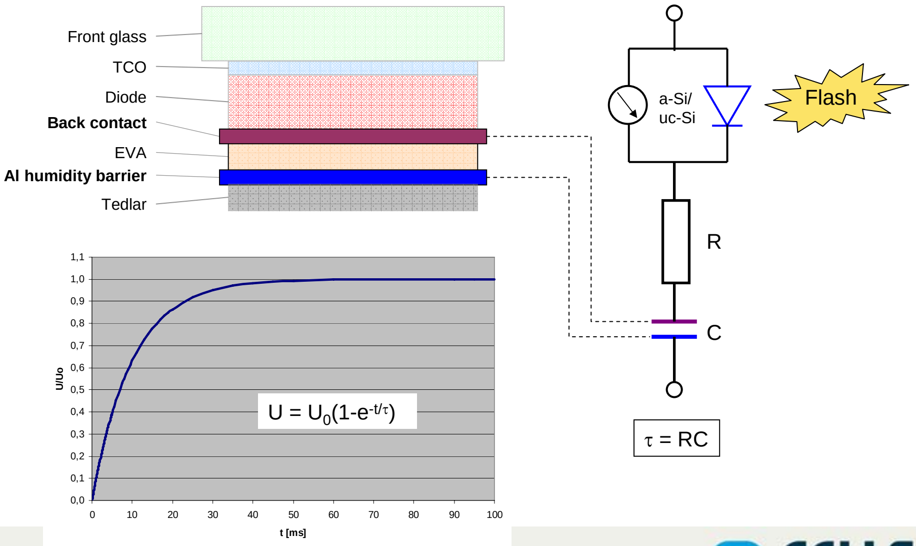
Flash tester - Illumination time

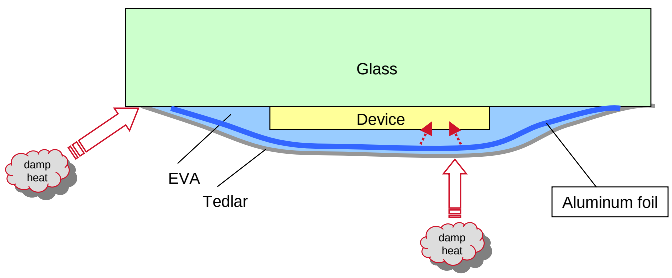


THANK YOU

Issues for discussion

- Flash tester
  - Spectrum
  - Uniformity
  - Illumination time
- Stability
  - Edge sealing
  - Barrier
  - Encapsulant
- Cost reduction
  - Encapsulation

Stability issues



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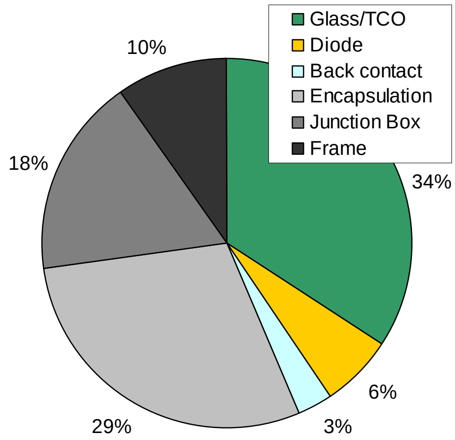
Material costs



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Q.CELLS

THANK YOU

Q.CELLS

Problems experienced in industry during the peak power and energy yield determination of thin-film modules

Ronald van Zolingen

"2nd Thin-films in Photovoltaics" Industry workshop, Ispra, November 9-10,2006

AVANCIS-Shell International Renewables

Importance of the subject

For the development of the thin-film PV industry it is essential to have:

- adequate procedures for the accurate determination of both the power and energy performance of thin-film modules
- adequate reference devices for measurement of irradiance

AVANCIS-Shell International Renewables

Type of measurements

- I-V curves and (peak) power measurements
  - on laboratory scale (steady-state simulator)
  - in production (steady-state or pulsed simulator)
- Outdoor irradiance measurements in the field to determine the "intrinsic" Performance Ratio and for detailed system yield analysis

AVANCIS-Shell International Renewables

Issues

- Type of reference devices
- Size of reference devices
- Stability of reference devices
- Calibration procedure for reference devices
- Effect of pulse duration of IV-curves if pulsed simulations are used

AVANCIS-Shell International Renewables

Procedure often used for calibration of solar simulation in case of CIGS

- Use of CIGS reference module to calibrate solar simulator
- Use of internal crystalline silicon cells to set the irradiance level
- Periodic use of CIGS reference module for calibration check

- Strong preference: Size of reference module equal of size of modules to be tested

AVANCIS-Shell International Renewables

Calibration of CIGS reference modules (at calibration institute)

- Indoor
  - Use of steady-state simulator
  - Spectral mismatch factor needs to be calculated implying that the spectral response needs to be known
  - Not dependent on weather conditions

- Outdoor
  - No spectral correction required if conditions are close to AM 1.5
  - Direct calibration against secondary reference device
  - Dependent on weather conditions

AVANCIS-Shell International Renewables

Spectral response measurements on CIGS modules

- It is not (yet) possible to execute spectral response measurements on larger areas (modules), at most laboratories
- It is difficult for industry to prepare small area devices for spectral response measurements
- It is not yet fully clear whether the JRC method for the determination of the spectral response with the Pasan pulsed simulator can be applied to CIGS modules

AVANCIS-Shell International Renewables

Concluding remarks

- It is important to reduce the uncertainty in the power and energy measurements of thin-film modules in general and of CIGS modules in particular, as much as possible
- It is important that spectral response measurements can be executed on a module level
- It is important to get insight in the effect of the ‘pulse duration’ on the I-V curve if a pulsed solar simulator

AVANCIS-Shell International Renewables

SOLIBRO

The Company

Progress

Performance

Peter Neretnieks
Solibro AB
Uppsala, Sweden

SOLIBRO

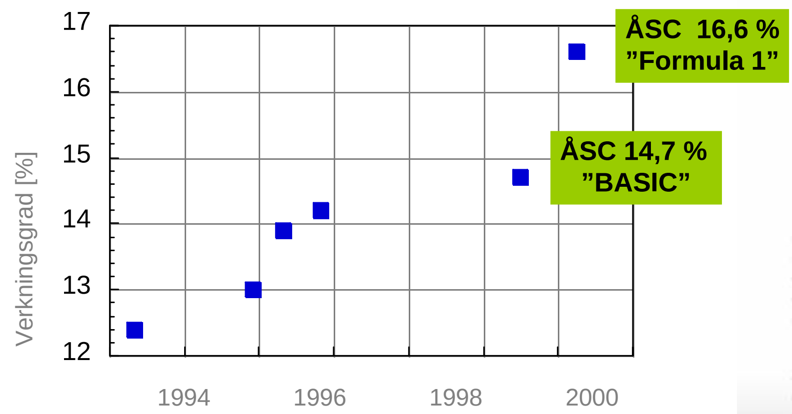
The company

- Commercialiasation of thin film solar module technology developed at the Ångström Solar Center – a research program at the Uppsala University financed by the Swedish Energy Agency and the Foundation for Strategic Environmental Research
- Founded 2000 by four persons active in the research program
- Start of operations September 2003
- Today 9 employees
  - Own facility with main part of operations
  - Agreement with Uppsala University giving access to certain research equipment at the university lab

SOLIBRO

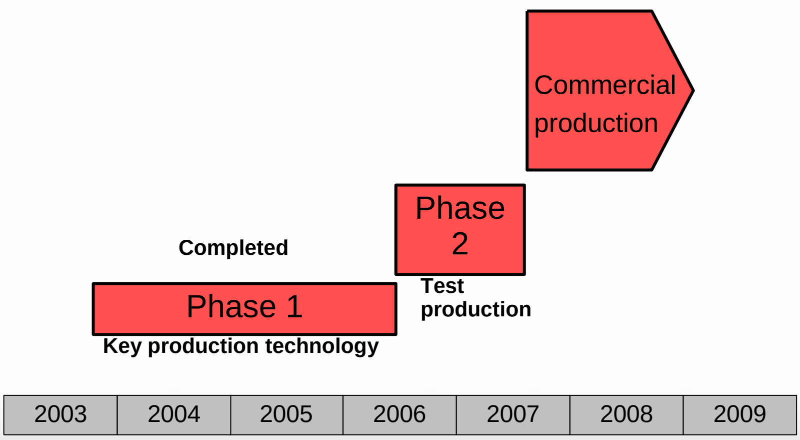
Our CIGS technology

World record for a thin film solar cell module



SOLIBRO

Development plan



SOLIBRO

Phase 1, completed

Achieved

– CIGS evaporator installed and running
– Uniformity of CIGS layer on 60 by 120 cm
– Throughput
– 30 x 30 cm modules (12 %) from cut down 60 by 120

SOLIBRO

Phase 2 – Test production

- Fastest route to complete production
  - 0,5 MW annual capacity
  - 12 % efficiency on 60 by 120 cm module
  - Demonstration of product
  - Reference installations

Phase 2 – where we are today

In operation

- CIGS production machine 60 by 120 cm

Machines ordered

- Chemical bath deposition for 60 by 120 cm modules
- Scribing for 60 by 120 cm modules
- Zinc oxide sputter for 60 by 120 cm modules

Phase 2 – where we are today

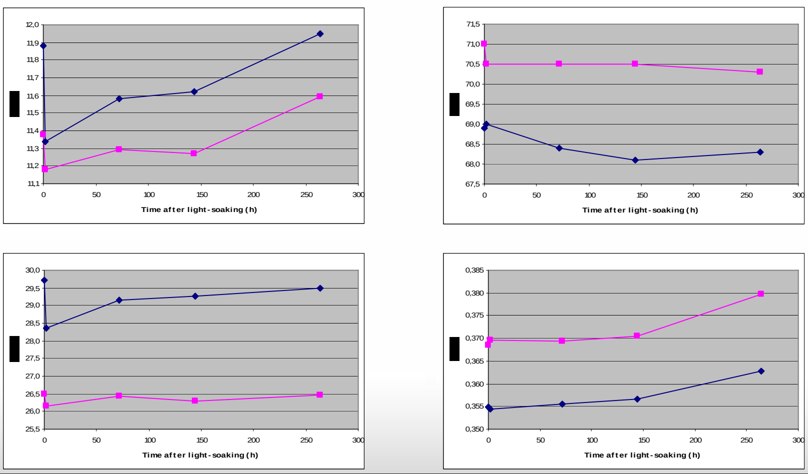
Evaluating machines and processes

• Edge deleting	-sandblasting, grinding, laser
• Tabbing	-gluing, welding, bonding
• Laminating	-PVB, EVA, TPU, …, …
• Framing	-profile, crimping, rivet, …
• Contact boxes	-sealing, epoxy, silicon, PU, …
• Testing	-lightsoaking, …
• IEC 1646	

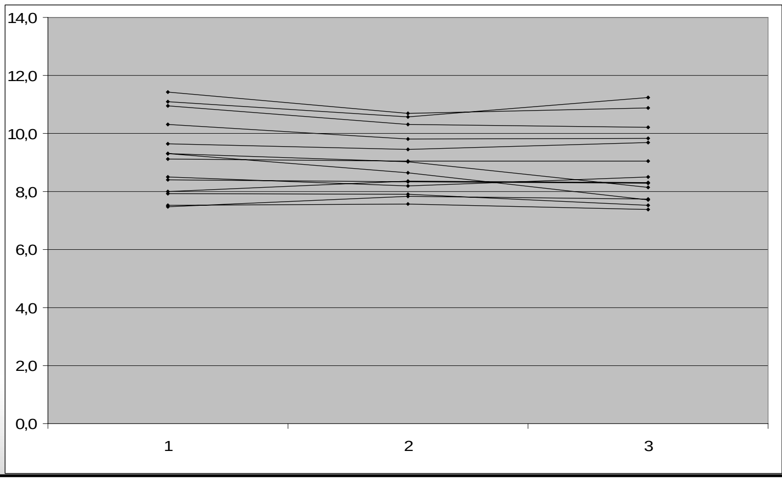
Performance

- Indoor lightsoaking 1/2 hour
- Outdoor lightsoaking 2 hours
- Outdoor performance
- 96 hours of lightsoaking at ESTI
- Conclusions

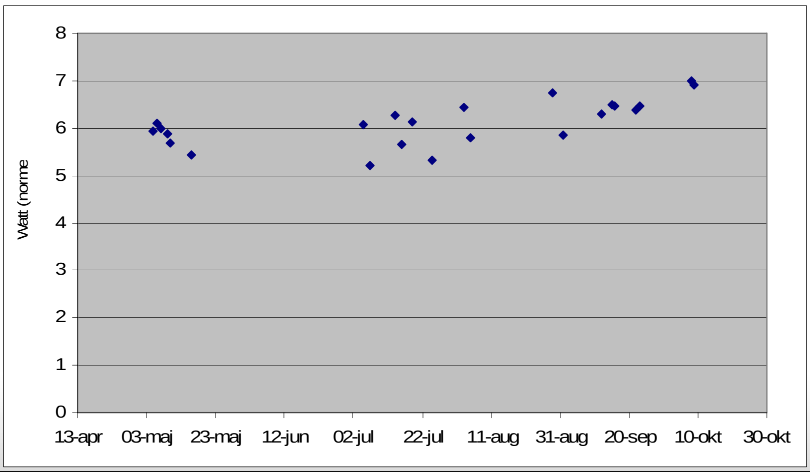
30 min of lightsoaking at T = 0

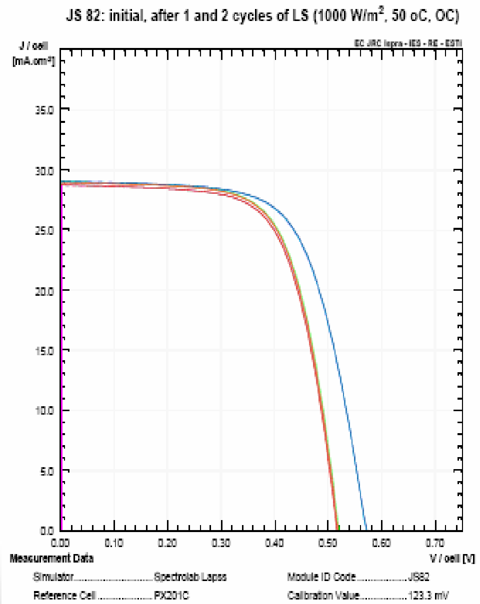


Before, 2 hours after and 240 h after 2 hours of out door lightsoaking



Efficiency May-October, 30 by 30 module





Conclusions

- Performance seems to drop after lightsoaking,
- Performance seems to increase with time

Pilot Production of Large-Area $CuInS_2$-Based Solar Modules

Alexander Meeder

2^{nd} International Photovoltaic Industriy Workshop on Thin Films

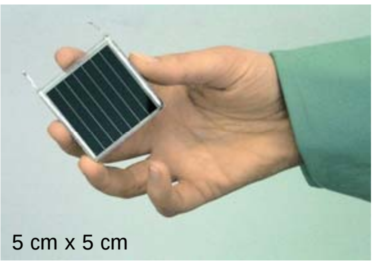
9 & 10 November 2006, JRC/IES, Ispra, Italy

Sulfurcell Solartechnik GmbH
Barbara-McClintock-Str. 11
12489 Berlin
www.sulfurcell.com

SULFURCELL

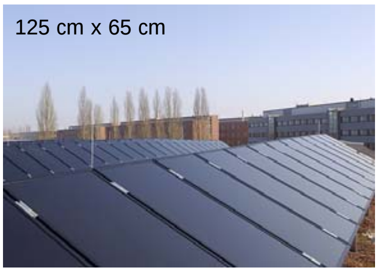
Introduction

- ***Hahn-Meitner-Institute has been developing $CuInS_2$-based technology since 1990***
  - ***5 cm x 5 cm modules***
  - ***Up to 10 % conversion efficiency***



5 cm x 5 cm

125 cm x 65 cm

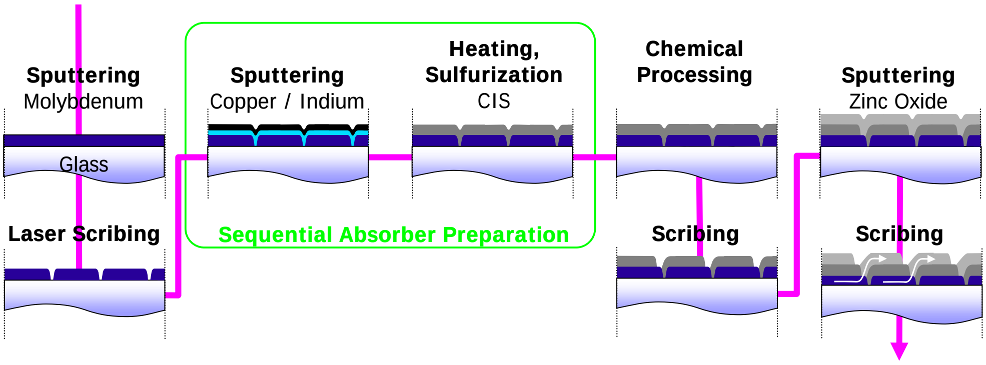


- ***Sulfurcell founded its scale-up/pilot production project in 2003***
  - ***2005: First 125 cm x 65 cm prototype***
  - ***2006: Begin of pilot production***

SULFURCELL

Production process for CIS-based solar modules

- Cell structure: $Mo/CuInS_2/CdS/ZnO$ (no use of Ga or Se, no control of Na)
- Sodalime glass as substrate material
- Encapsulation: Cover glass laminated onto substrate glass at T_{max} = 150 °C
- Sputtering of Mo, Cu, In, ZnO for preventing large-area homogeneity problems
- Rapid thermal processing of Cu/In in a sulfuric atmosphere
  - T_{max} = 550 °C, process time < 5 min



Highest power output to-date from a 125 cm x 65 cm module: 60 W

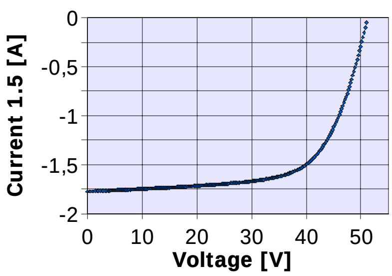
A = 0.74 sqm (Aperture Area)

Eff = 8.2 %

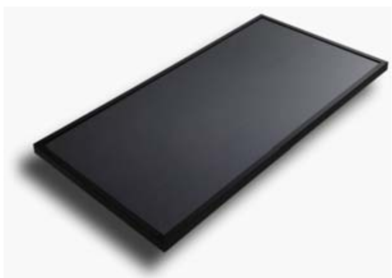
Voc = 51.2 V

FF = 66.0 %

Isc = 1.78 A



Layout:
80 interconnected cells



SULFURCELL

Homogeneity optimization: The prospective key to 72 W_p from a 125 cm x 65 cm module (aperture area eff = 9.7 %)

Comparison of HMI cells and modules (lab) to those of the Sulfurcell pilot production

Type		**Cell**		**Module**	
Manufacture		**Lab**	**Production**	**Lab**	**Production**
Area	[sqcm]	**0.5**		**5 x 5**	**121 x 61**
Eff	[%]	11,4	9,8	9,7	8,2
Voc	[mV/cell]	729	**690**	723	**640**
FF	[%]	71,7	69,2	66,6	66
Jsc	[mA/cm^2]	21,8	20,5	20,1	19,5

- Fill-factor/short-circuit current-density of production cells/modules approach laboratory values
- Open-circuit-voltage of production modules significantly lower than those of production cells

SULFURCELL

Page 5

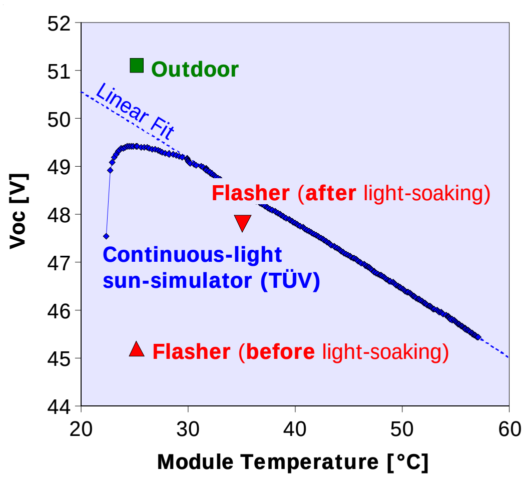
Light-soaking is a crucial prerequisite in obtaining an accurate power rating using a flasher-type sun-simulator

Illumination systems for power-rating

1. Industrial flasher (3 ms illumination time)
2. Continuous light (TÜV Rheinland)
3. Outdoor conditions (TÜV Rheinland)

Observations for laminated modules

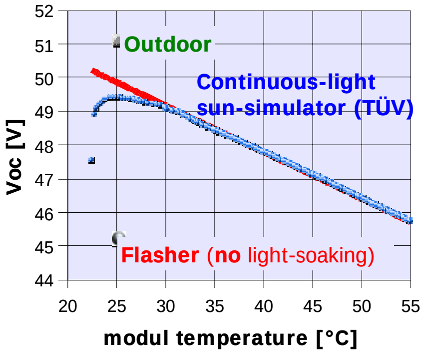
- Voc values obtained with flasher 10 % lower than outdoor values
- Temperature dependency of Voc (obtained during illumination by continuous-light sun-simulator) follows expected linear course not before 2 min illumination

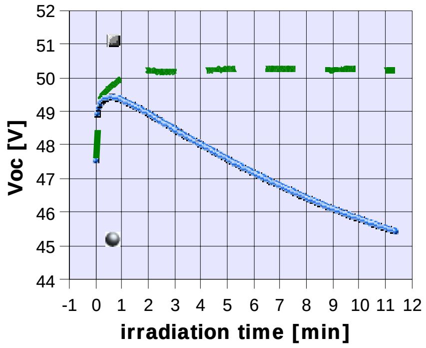


⇒ **Sulfurcell procedure**
(1) light-soaking → (2) Quick transfer → (3) Flasher test

Page 6

Comparison of flasher and open field Voc values at STC and separation of transient and temperature effect on Voc:





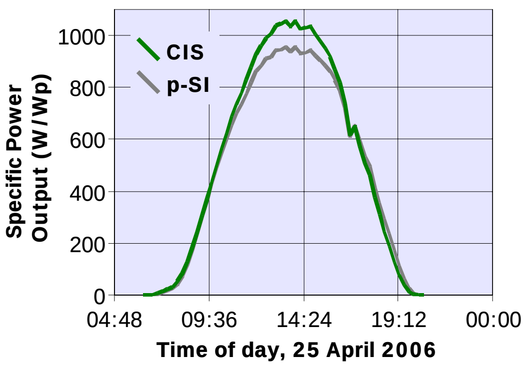
SULFURCELL

Outdoor performance proves power rating procedure

Sulfurcell field experiment

Two net-connected PV-systems with identical converters and orientation:

- 1 kW_p equipped with polycrystalline silicon (p-Si) type solar modules
- 1 kW_p equipped with $CuInS_2$-type solar modules (Power rating based on flasher-based IV measurement after light-soaking)



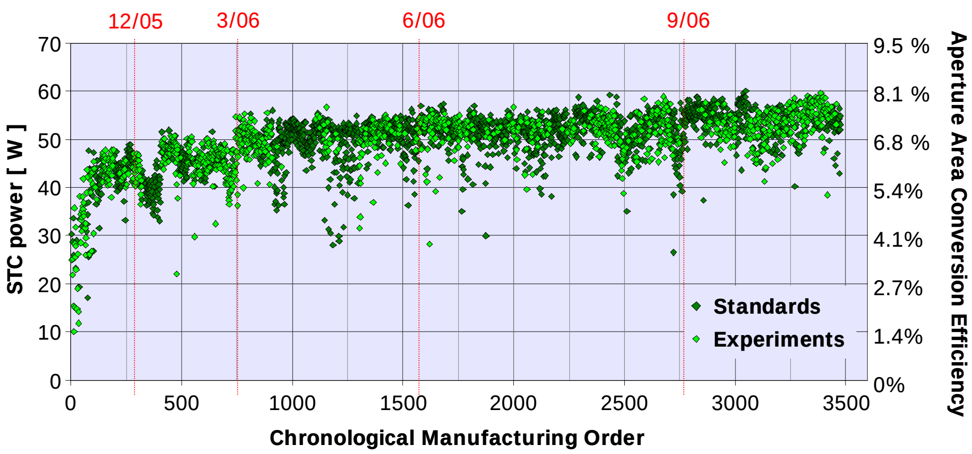
Pilot production: > 3.000 modules equalling 150 kW produced since 10/05

- Standardardized manufacturing process established in October 2005
- Standard process parameters modified whenever an advantage is statistically legitimated
- Present production volume: 1000 modules per month
- 5 MW production ramp-up underway

SULFURCELL

Page 9

Pilot production learning-curve: Continuous improvement of efficiency



SULFURCELL

Page 10

Summary

- ***Scale-up of $CuInS_2$-based technology from 5 cm x 5 cm to 125 cm x 65 cm successfully completed***

- ***8.2 % efficiency already achieved even without optimization of homogeinity and window layer***

- ***Pilot production of the first three thousand modules (150 kWp) (≈ 25 month after installation of equipment)***

- ***Excellent outdoor performance (in spite of light-soaking effects after short illumination times)***

SULFURCELL

Page 11

Industrialisation of CIS Technology At Würth Solar

www.wuerth-solar.de

Bernhard Dimmler
Würth Solar GmbH & Co. KG
Schwabisch Hall / Germany

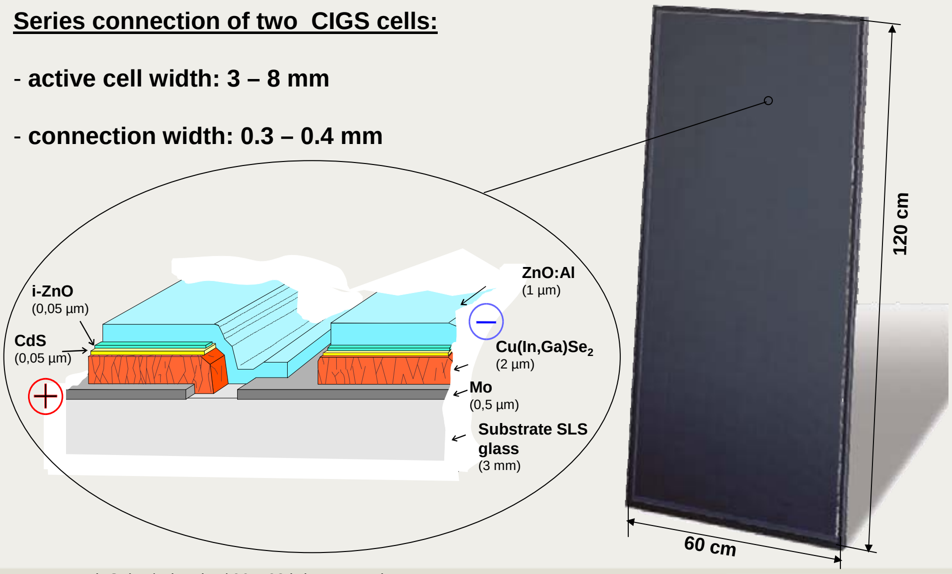
Würth Solar a PV company within the Würth Group

Worldwide sales of fixing and assembly materials and tools Turnover in 2005 ~ 6.9 billion Euro employees ~ 50,000	Division Würth Electronics Circuit Board Technologies & Photovoltaics (Würth Solergy) Turnover in 2005 ~ 240 million Euro employees ~ 2,100	Photovoltaics Production of CIS thin film PV modules Turnover in 2005 ~ 5.2 million Euro employees ~ 65

The CIS Thin Film Module

Series connection of two CIGS cells:

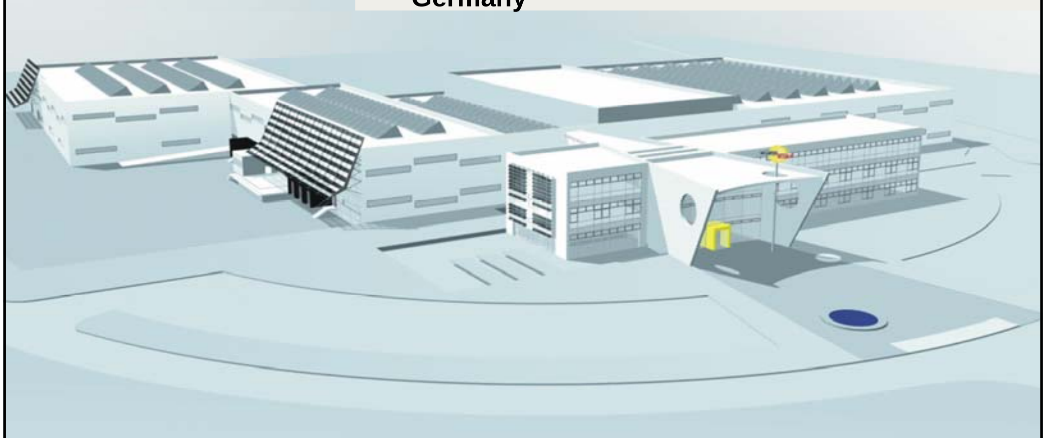
- active cell width: 3 – 8 mm
- connection width: 0.3 – 0.4 mm



3 Würth Solar / Dimmler / 061108 bd TF PV Industry company

THE Plan

in Schwabisch Hall, Baden-Wurttemberg Germany



4 Würth Solar / Dimmler / 061108 bd TF PV Industry company

THE REALITY

Front View June 2006

: Facts & Numbers

- Ramp-up in second half of 2006, full production from January 2007 onwards (Pilot line in Marbach is shut down completely)
- Current status:
  - production ramp up successful
  - First series of CIS modules with high quality
- Module size: 60 cm x 120 cm (same as in pilot line)
- Production capacity: 15 MWp/a = about 200 000 modules per year
- Investment: 55 million €
- Size of building incl. offices and warehouse: 22 600 m2
- Employees: 125, full-shift operation

THIN-FILM MODULE TESTING

T. Sample
European Commission, DG Joint Research Centre
Institute for Environment and Sustainability
Renewable Energies Unit,
Ispra, Italy

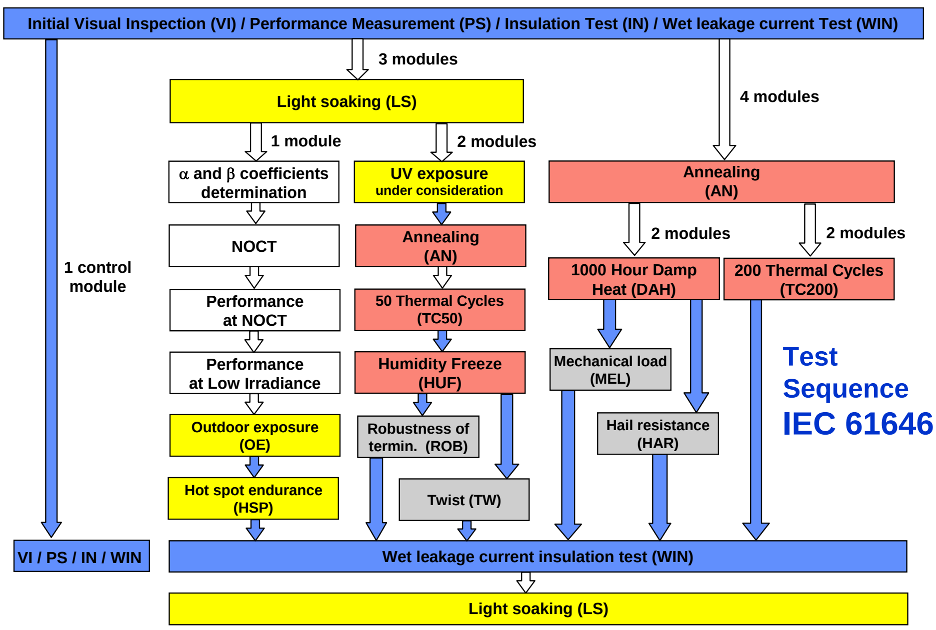
Thin-Film workshop, November 9-10, 2006 Ispra, Italy

Introduction

- **Module Lifetime is one of the four factors determining cost of PV electricity**
- **Accelerated testing is used to**
  - Build-up User Confidence
  - Warranty issues
- **Testing by acceleration of mechanical and temperature (humidity) extremes**

IEC Standard 61646

- **Published in 1996**
- **Thin-film terrestrial photovoltaic (PV) modules - Design Qualification and Type Approval**
  - "It is written with amorphous silicon technology in mind, but may also be applicable to other thin-film PV module"
  - "Modifications to the test sequence may be necessary due to the specific characteristics of these other new technologies"



Test Sequence IEC 61646

Pass/Fail Criteria

- **Modules fail with**
  - Visible major defects
  - Circuit Faults (Open Circuit or Grounding)
  - Performance Loss > 5%/8%
  - Insulation Failures
- **Between the tests:**
  - Visual Inspection, Performance and Insulation tests
  - Wet insulation at the beginning and end
- **After final light-soaking, the maximum output power at STC is not less than 90% of the minimum value specified by the manufacturer.**

Types of Modules Tested

Commercial testing at ESTI:
- **Single junction a-Si, Tandem, Triple Junction**

Testing of prototypes
- **Single junction a-Si, Tandem**
- **Cadmium Telluride**
- **CIS**

Some Specific Thin-Film Issues

- **Insulation failures due the use of TCO layers**
  - Require effective edge cleaning to avoid problems
- **Power stability following a single test**
  - Leading to failure (i.e. greater than 5% loss)
  - However, final light soaking shows recovery of power

7 ☼ Renewable Energies

JOINT RESEARCH CENTRE EUROPEAN COMMISSION

- **Out-gassing during DAH**
  - 1000H continuous 85°C / 85 rh (Failure)
  - Sequential testing does not cause the same effect?

8 ☼ Renewable Energies

JOINT RESEARCH CENTRE EUROPEAN COMMISSION

Revision of the Standard In Progress

A number of modifications:

- Removal of the power requirement after each test
- Introduction of the bypass diode thermal test
- Modification of the insulation tests to account for the size of the module

  (for modules with area larger than 0,1 m^2 the measured insulation resistance times the area of the module shall not be less than 40 $M\Omega \cdot m^2$)
- Wet Insulation test within 4 hours of the Damp Heat test
- Changes to the shading of cells in the Hot Spot test
- NOCT at a fixed angle 45^o

2nd International Photovoltaic Industry Workshop on Thin Films

9 & 10 November 2006
JRC/IES, Ispra, Italy

Preconditioning, Measurements and Testing of Thin Film Modules

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1

Specific characteristics regarding measurement and testing

Multi-junction structure	⟷	**Calibration procedures**
Sensitivity to light exposure and temperature treatment	⟷	**Reference devices**
Transient and pre-conditioning effects	⟷	**Measurement procedures (indoor/outdoor)**

↓ ↓

Comparable and reproducible results

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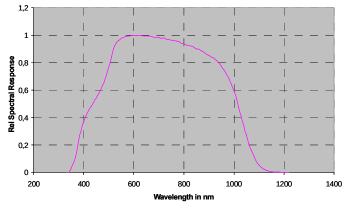
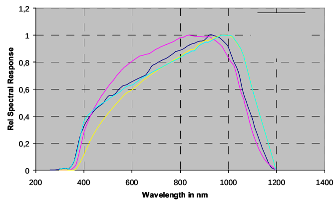
Specific characteristics regarding measurement and testing

Relative spectral response curves of TF devices

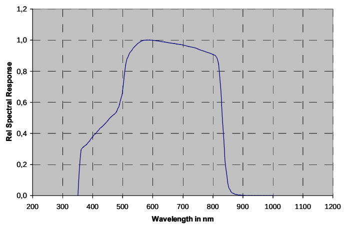
CIS



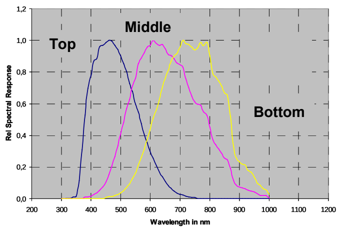
a-Si



CdTe



a-Si/a-Si/a-Si



Ongoing European activity in PERFORMANCE IP

Sub-project 1:
Traceable performance measurements of PV devices

Objectives:
…
Adaptation/development of measurement procedures for thin film PV devices and new technologies
…

Task 1.1:
Round robin test with commercially available TF modules:
a-Si (single, double, triple), a-Si/µ-Si, CIS, CdTe

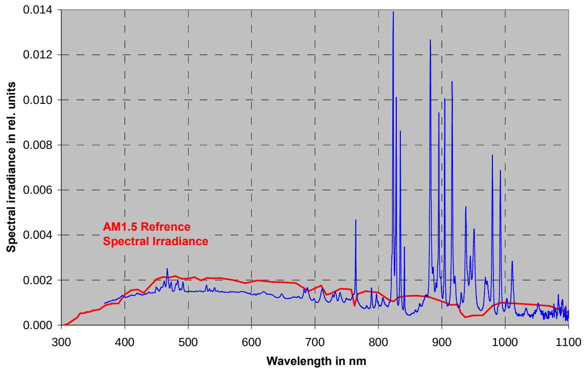
8 Participating labs:
Arsenal, Ciemat, CREST, ECN, ISE, JRC, SUPSI, TUV

Interim results: Mid 2007

Use of solar simulators for performance measurement

Non-filtered pulsed Xenon lamp

Aim: **Effective irradiance for TF technology = Target irradiance**
Irradiance correction of I-V data points should be kept small

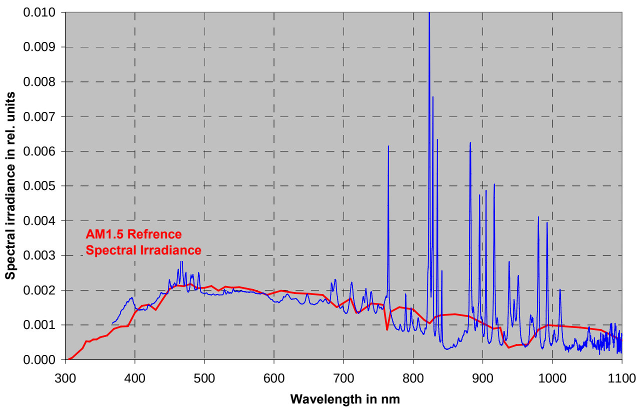


Technology	E_{EFF}
c-Si	**1000 W/m²**
a-Si	680 W/m²
a-Si/a-Si	710 W/m²
a-Si/a-Si/a-Si	660 W/m²
a-Si/µ-Si	690 W/m²
CIS1	960 W/m²
CIS2	980 W/m²
CdTe	700 W/m²

Considerable irradiance correction to E_{EFF} = 1000 W/m² may become necessary ⇔ Uncertainty due to scattering of module irradiance correction parameters

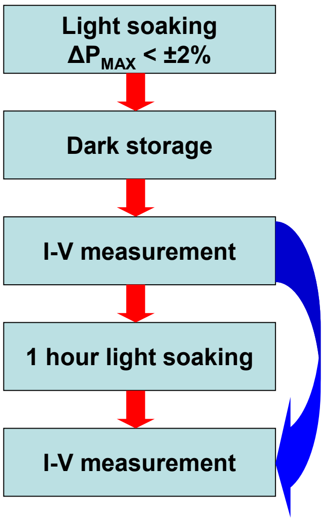
Use of solar simulators for performance measurement

Filtered pulsed Xenon lamp



- **Better match to AM1.5**
- **Influence on E_{EFF} is currently investigated for different TF technologies (better ratios c-Si/TF expected)**

Indoor performance measurement
Preconditioning effects

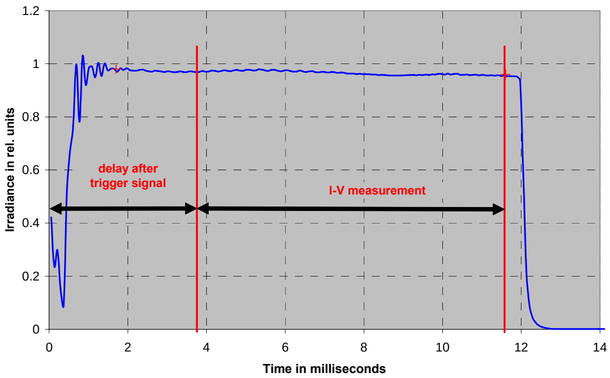


P_{MAX} change due to 1 hour LS

a-Si	-0.3%
a-Si/a-Si	+0.2%
a-Si/a-Si/a-Si	TBD
a-Si/µ-Si	-0.8%
CIS1	-2.2%
CIS2	+17.2%
CdTe	+3.6%

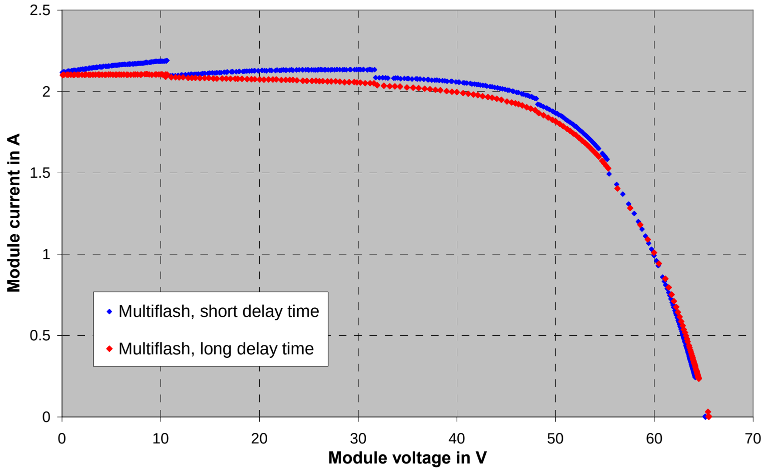
- **TF technologies show a very specific behaviour**
- **Test conditions for short-term light soaking not clear**
- **a-Si Technologies seem to be less critical**

Indoor performance measurement
I-V measurement techniques for pulsed solar simulators

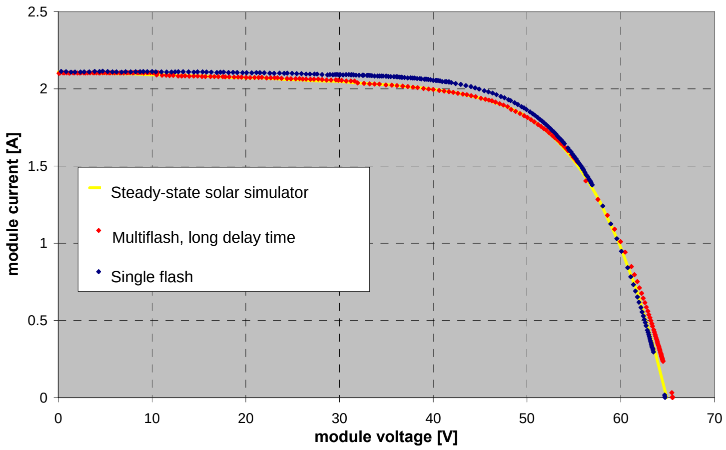


Type of measurement	Flash	Delay	I-V	Total I-V
Single flash measurement:	1	1.7	9 ms	9 ms
Multi-flash measurement:	5	1.7 ms	9 ms	45 ms
Multiflash measurement:	5	8.2	1.8 ms	9 ms

Indoor performance measurement
I-V measurement techniques for pulsed solar simulators



Indoor performance measurement
I-V measurement techniques for pulsed solar simulators



Performance measurement

Temperature and irradiance correction procedure

$$I_2 = I_1 \cdot [1 + \alpha \cdot (T_2 - T_1)] \cdot E_2 / E_1$$

$$V_2 = V_1 + V_{OC1} \cdot [\beta \cdot (T_2 - T_1) + a \cdot \ln(E_2 / E_1)] - R_S \cdot (I_2 - I_1) - \delta \cdot I_2 \cdot (T_2 - T_1)$$

Legend:

I_1, I_2: Module current
V_1, V_2: Module voltage
T_1, T_2: Module temperature
E_1, E_2: Irradiance

Index 1: Measurement conditions
Index 2: Corrected conditions

Module parameters:

α : Temperature coefficient I_{SC} [1/K]
β : Temperature coefficient V_{OC} [1/K]
R_S : Series resistance [Ω]
a : Irradiance correction factor
δ : Temperature coefficient R_S [Ω/K]

Temperature coefficients are related to I_{SC} and V_{OC} @ STC

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Performance measurement

Temperature and irradiance correction parameters

- Parameters determined from steady-state simulator measurements
- Translation accuracy <±1%

PV module technology	TC (Isc) 1/K	TC (Voc) 1/K	a	Rs mΩ	δ mΩ/K
a-Si	0.000942	−0.00329	0.0522	7121	−152
a-Si/a-Si	0.000979	−0.00367	0.0484	1040	−8.9
a-Si/a-Si/a-Si	0.001020	−0.00398	0.0590	418	−10.5
CdTe	0.000423	−0.00116	0.0256	7925	−12
CIS 1	0.000098	−0.00273	0.0480	1730	−8.9
CIS 2	0.000000	−0.00381	0.0770	9	−10.1
a-Si/µ-Si	0.000832	−0.00333	0.0580	1775	−45
c-Si	0.000346	−0.00250	0.0340	624	2.4

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Conclusions

- Harmonised measurement methods for TF modules are not available
- Development of technology specific measurement procedures is required (pre-treatment, measurement parameters etc.)
- Modification of measurement equipment may become necessary

Scientific work under PERFORMANCE IP is aiming to fill this gap

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Photovoltaics

Constant Light Source

Leading Technology for Solar Energy

Goals of testing

- Accurate measuring of the module performance at a given time in the production cycle
- Repeatability of the cell behaviour after the measurement

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Light-soaking of thin-film technologies
Example: CdTe

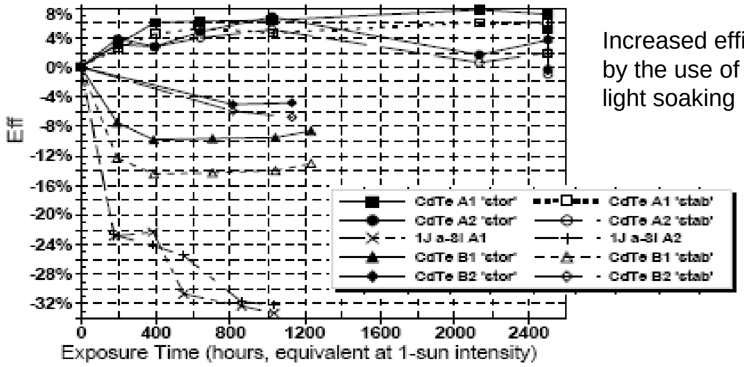


Fig. 1. Relative changes (%) in open-circuit voltage, fill factor, and efficiency at SRC, respectively, at top, middle, and bottom portions, plotted against exposure time for four CdTe modules, plus two a-Si single-junction modules.

Increased efficiency by the use of light soaking

J.A. del Cueto, et al. NREL **National Renewable Energy Laboratory** *2004 DOE Solar Energy Technologies, Program Review Meeting, October 25-28, 2004, Denver, CO, USA*

Light-soaking of thin-film technologies
Example: a-si

amorphous-Si:H

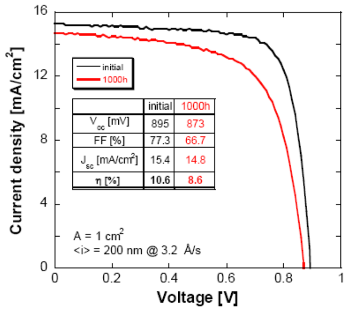


Figure 1: Best amorphous p-i-n test cells in the initial and light-soaked state processed in a small R&D single-chamber KAI-M reactor. As front TCO Asahi U-type SnO_2 was applied.

micromorph (a-Si:H/μc-Si:H)

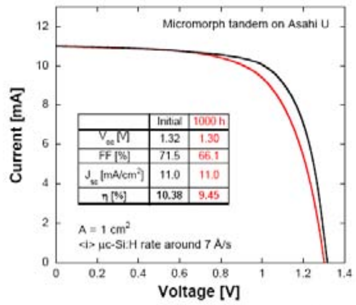
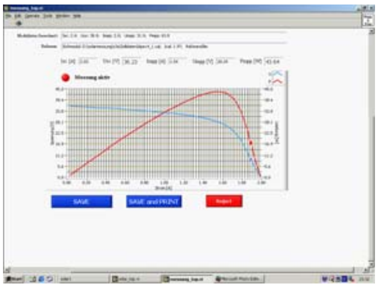


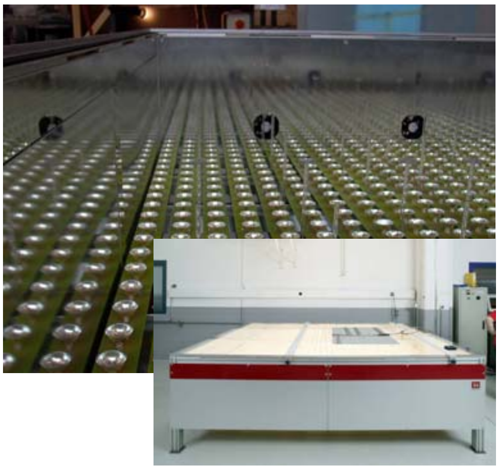
Figure 11: AM1.5 I-V characteristics of an initial and degraded micromorph (a-Si:H/μc-Si:H) tandem solar cell deposited in small KAI reactors (top cell deposited in KAI-M and bottom cell deposited in KAI-S at IMT).

U. Kroll et al., OC Oerlikon Balzers Switzerland, 21st EU-PVSEC (Dresden 2006)

The degradation is caused by Staebler-Wronski effect which is even reversible.

3S MT2416





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Solar Simulator Type: 3S
Classification = XBA

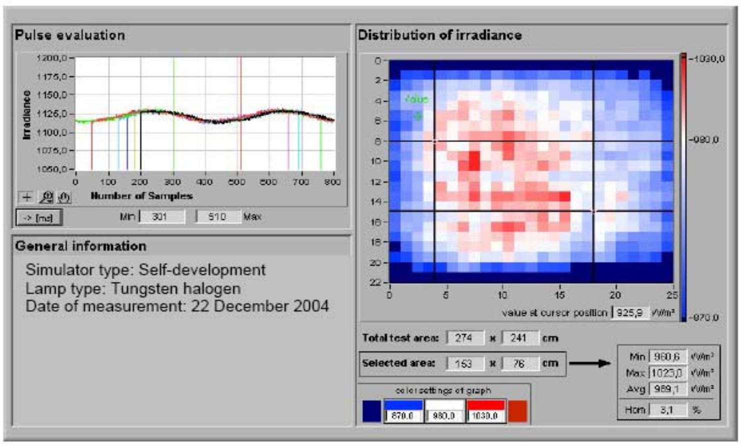

Figure 1: Uniformity of irradiance in the designated test area <5%
⇨ Classification = B
Temporal instability <2% for simultaneous measurement of irradiance, module voltage and module current for each I-V data point
⇨ Classification = A

Spectral missmatch halogen lamp tester

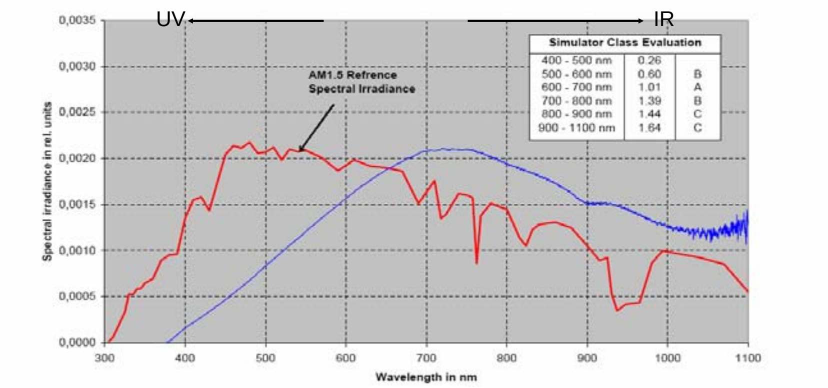

Figure 2: Spectral match with AM1.5 lies outside the range of 0.4 to 2.0
⇨ Classification lies outside class C ⇨ X

Overview

Disadvantages

- Power consumption of the system
- Spectrum is not AM1.5
- Heat up of the cell during the measurement pulse

Advantages

- Transient effects are not exisiting due to DC behaviour

Further information

3S Swiss Solar Systems AG
Schachenweg 24
3520 Lyss
Switzerland

www.3-s.ch

Tel. ++41 32 387 10 10
Fax. ++41 32 387 10 11

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1960

Hans-Jürgen Berger developed the company's first flashers for photography.

These units are distributed worldwide by ROLLEI-Werke Braunschweig since 1968.

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The **Rollei E5000** was the first flasher used for solar simulation in 1973. MBB used it to test panels.

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A more powerful flasher of up to 24.000Jl was built in 1976.

Since that time the standard set up contains a generator, light source, measuring electronics and a computer with printer.

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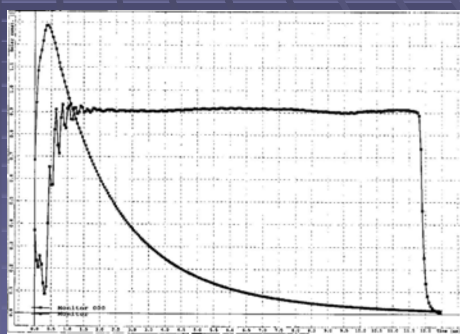
The disadvantage of photographic flashers is the uncontrolled light discharge curve.



Berger **P**ulsed **S**olar **S**imulators use current control electronics to stabilize the illumination during a max. measuring time.

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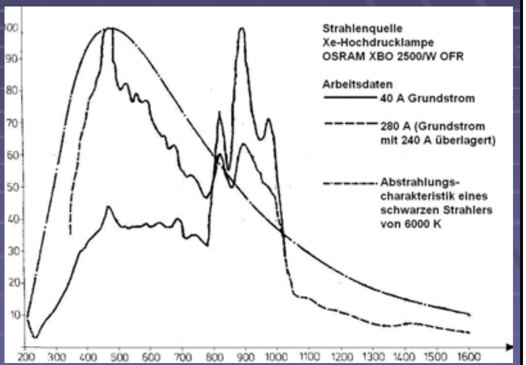
Like any other lamp type, **Xenon** lamps change their spectral distribution from red to blue by raising the current

A constant current brings a constant spectrum



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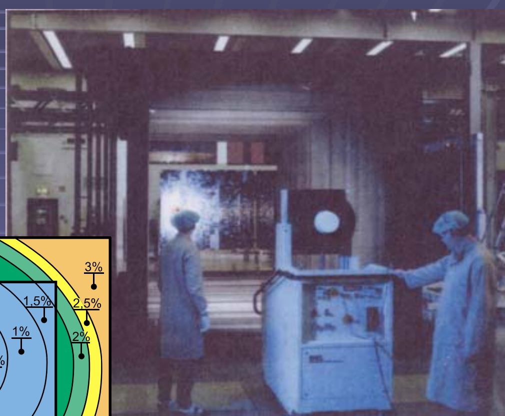

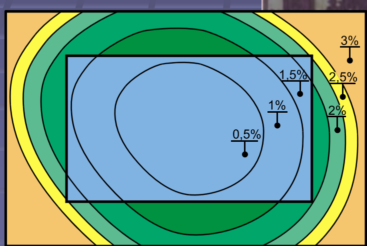

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A full passive load decay allows reproducible measurements as well as traceable documentation

Windows compatible software can be easy integrated into automatic production or a monitoring system with remote access

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Our philosophy is:

Full Passive measuring

Stable illumination with lowest influence from aging

Minimum recalculation of data points to STC

No IV-Curve fitting

This is the base of our testing for advanced technologies like:

High Efficiency, Multi Junction and Thin Film

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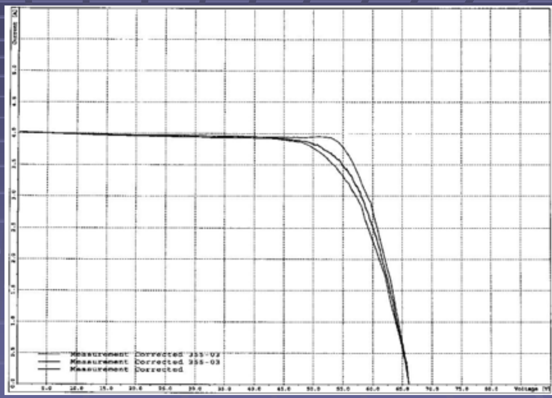
An often discussed effect:

A High sweep rate shows different results as the effect of different sweep directions.

A typical effect of high efficiency cells only?

Are there additional effects from the measuring system?



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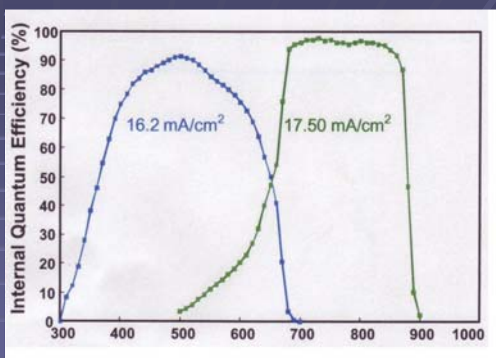
A less discussed effect :

The current limiting effect in a Multi Junction Cell

How big will be the influence be on the measurement results?

Is it necessary to adjust the spectral distribution?



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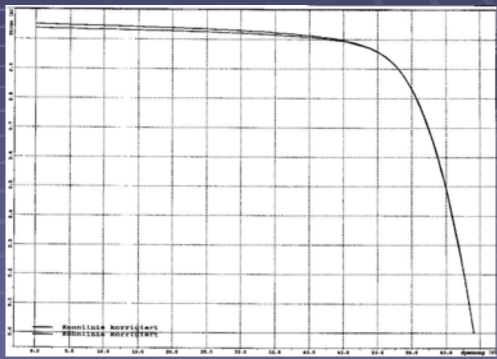
The current limiting effect in a Multi Junction Cell

By a wrong recalculation of the **I**sc the **F**ill **F**actor is incorrect as is the **P**mpp

Only a reproducible and traceable setup can help to verify product improvement and allow comparisons to other products and technologies.



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Low irradiance measurements can recover additional effects

Typically these effect are depend on **R**s

Again only a reproducible and traceable setup can help to verify product improvement and allow comparisons to other products and technologies.

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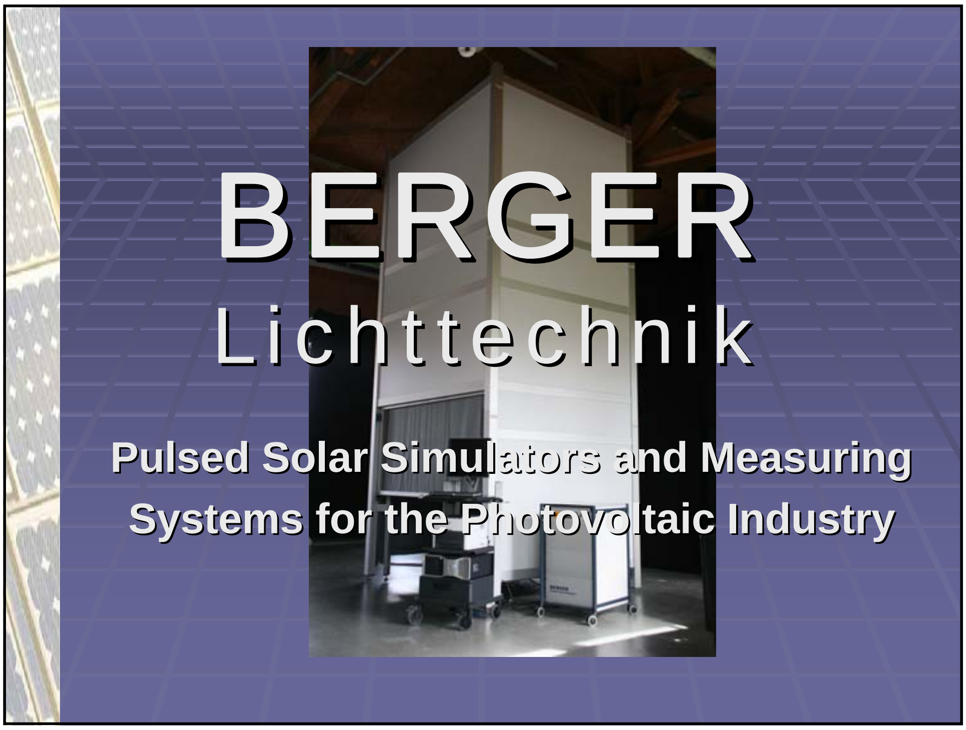
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Performance of Thin Film Modules

Keith Emery
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email:keith_emery@nrel.gov
Cell phone 303-880-2913

Measurements & Characterization Division

Cells: Coordinator: Tom Moriarty
Chuck Mack

Modules: Coordinator: Steve Rummel
Allen Anderberg
Laurence Ottoson

calibration lab support; ISO 17025 calibrations, spectral irradiance

Presented at "2nd International Photovoltaic Industry Workshop on Thin Films" 11/9-10/2006, JRC/IES, Ispra, Italy

National Center for Photovoltaics

NREL

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Goal

Determine Current *versus* Voltage
under Continuous Illumination
At 25 °C junction temperature
1000 W/m^2 total Irradiance
IEC Global Reference Spectrum

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Source of Differences

Procedural
- Calibration lab - formal
- Internal researchers - variable
- Manufacturers - marketing, Power Mark
- External can not distinguish between calibration lab and internal

Definition
- Area - total, active, aperture, typical, not measured

Data Acquisition System
- Voltage bias rate - too fast for pulsed systems
- Voltage bias direction - rarely both directions
  so hysteresis can not be detected

Pre-measurement conditions
- Voltage (0V,0A or P_{max}), light, temperature, humidity

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Total Irradiance

Because the reference spectrum has a small number of points (122) the total irradiance is a function of the integration method at the 0.2% level.

This is one of the reasons why my procedures treat total irradiance separately form the reference spectrum

The ratio of the normalized and unnormalized global reference spectrum should be constant but they differ by several % at certain wavelengths

New IEC reference spectrum will solve this issue

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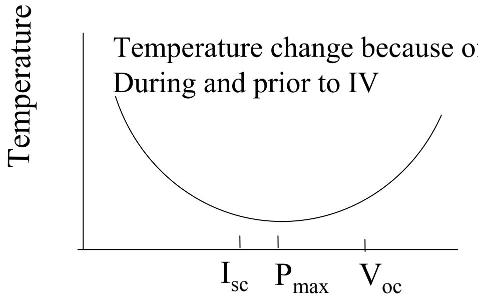
Light Trapping

A mono-crystalline solar cell's efficiency improves when encapsulated because the encapsulation utilizes a white border providing additional light to the cell via internal reflections. Other possibilities for thin films (reflection off edges).

Mask area cm^2	Border mm	Voc mV	Isc A	FF %	η %
unmasked	--	603.3	1.346	60.63	14.1
82.8	32	602.4	1.298	61.39	13.7
64.0	21	601.7	1.265	61.36	13.3
51.8	13	600.8	1.222	61.86	13.0
37.2	2	597.8	1.147	62.39	12.2
34.8	0	597.8	1.095	62.95	11.8

Temperature



You can not directly measure junction temperature. Temperature gradient between back surface & junction are a function of light level, air temperature, wind speed. Sensor error >±2°C for thermocouple/meter.

We measure temperature before and after IV curve and note change. Kept at Voc prior to IV

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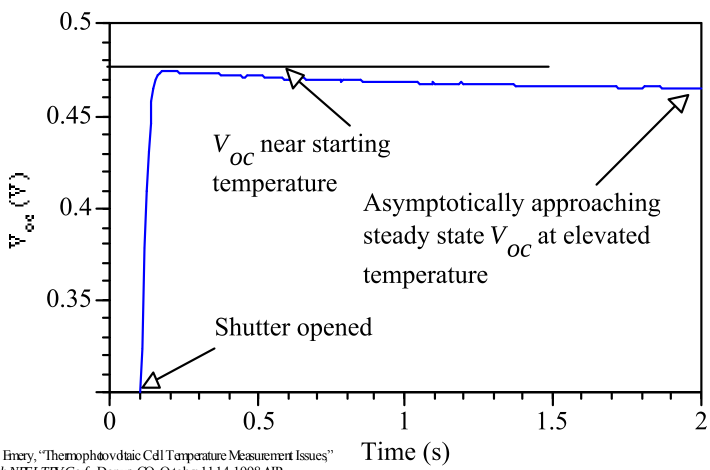
V_{oc} Temperature Determination



T. Moriarty and K. Emery, "Thermophotovoltaic Cell Temperature Measurement Issues" *Proc 4th NREL TPV Conf.*, Denver, CO, October 11-14, 1998, AIP proceedings 460, pp 301-311, 1998.

Bias Rate and Direction

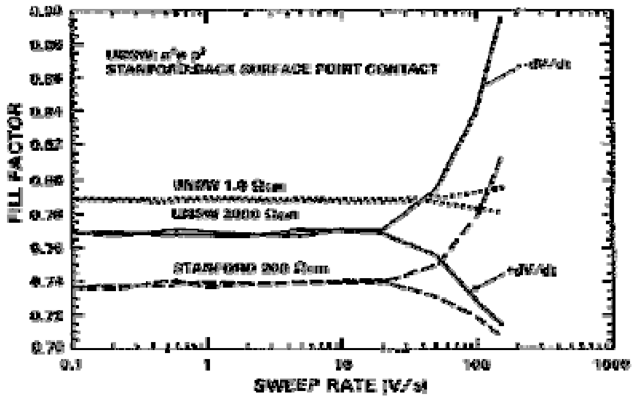


Fig. 2. Influence of voltage sweep rate and direction on measured fill factor of different silicon cells.

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k. Emery NREL

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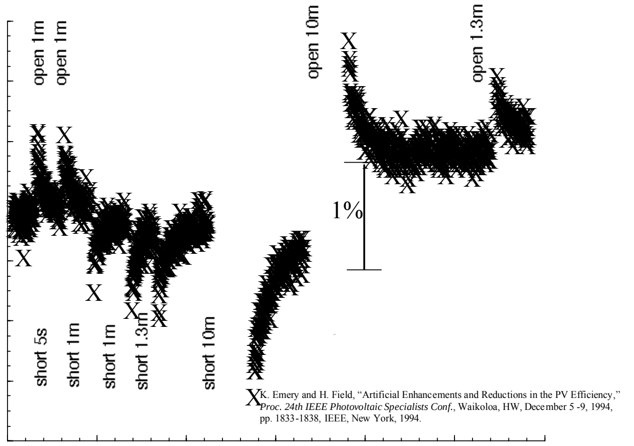
CdTe



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CIS

No changes in I_{sc}

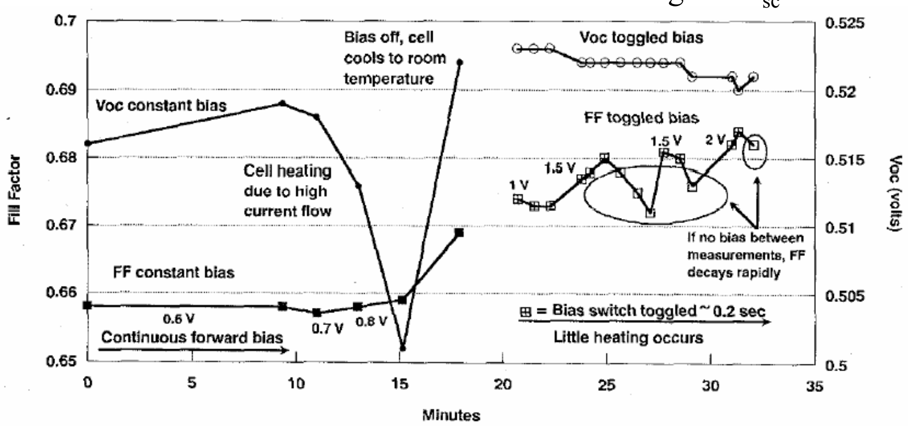

Fig. 3. Different dark forward bias methods applied to a cell that had previously been light soaked until the efficiency stopped increasing.

Siemens Solar, Proc. 23 IEEE PVSC, 1993,p. 495

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a-Si

Low light, low temp in winter -> degradation

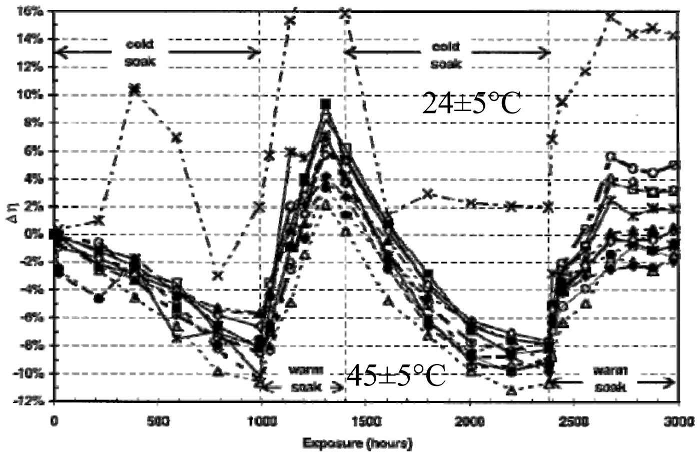

Figure 11. Relative efficiency changes (Δη) vs light exposure for both cold and warm soaks and both cycles I and II, compared to start-of-test values

NREL, Prog. In PV, **7**, p. 101, 1999

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NREL Methods

ISO 17025 accredited by A2LA #2236.01 for

Primary reference cell calibration (direct normal sunlight, cavity radiometer, spectral corrections, ASTM E1125)

Secondary reference cell calibration

Packaged cell, 4 wires, must be able to control temperature, temperature sensor attached, perform IV curve, QE with bias light, less than 20 x 20 cm, 1 mW to 600 W, 1 mA to 15A, single junction

Secondary module calibrations, must be able to measure QE on individual cell in module or representative cell provided. 120 x 150 cm, 50 mW to 1200 W, 100 mA to 50 A, Cell in module packages

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NREL Methods *(cont.)*

Use Si, filtered Si or GaAs primary reference cell for simulators. Si cell in module package secondary cell for outdoors.
Other cells for multi-junctions

Light soak thin film modules outdoors E > 800 Wm^{-2} for 10 to 30 min. or E > 0.2 $kWhrm^{-2}$

Measure on different test beds

Pulsed simulator, continuous simulator, outdoors

Apply spectral corrections prior to IV on simulators post IV for natural sunlight. Measure outdoors with irradiance within 5% of 1000 Wm^{-2}.

Monitor change in Voc and compare test beds for problems

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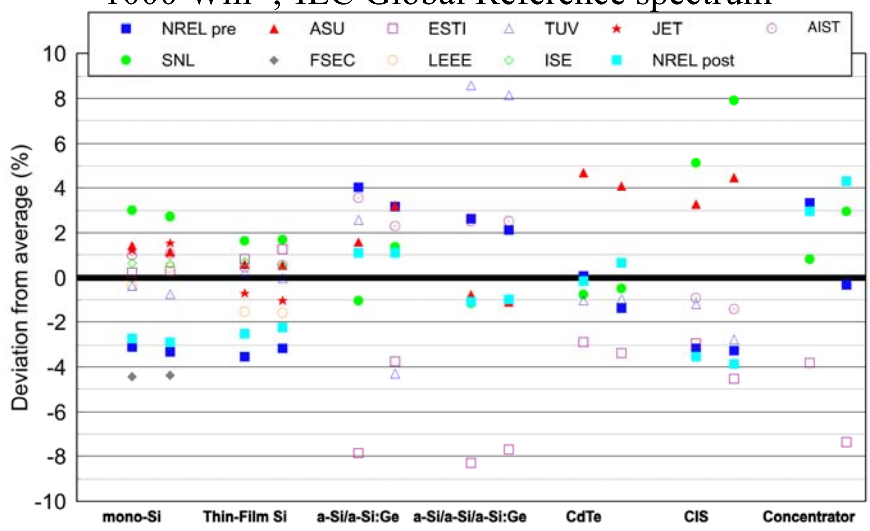
S. Rummel, A. Anderberg, K. Emery, D. King, G. TamizhMani, T. Arends, G. Atmaram, L. Demetrius, W. Zaaiman, N. Cereghetti, W. Herrmann, W. Warta, F. Neuberger, K. Morita, and Y. Hishikawa, "Results from the Second International Module Inter-comparison," *Proc. IEEE 4th World Conference on Photovoltaic Energy Conversion, May 7-12, 2006 Waikoloa, HI.*

Results - P_{max} @ 25 C, 1000 Wm^{-2}, IEC Global Reference spectrum



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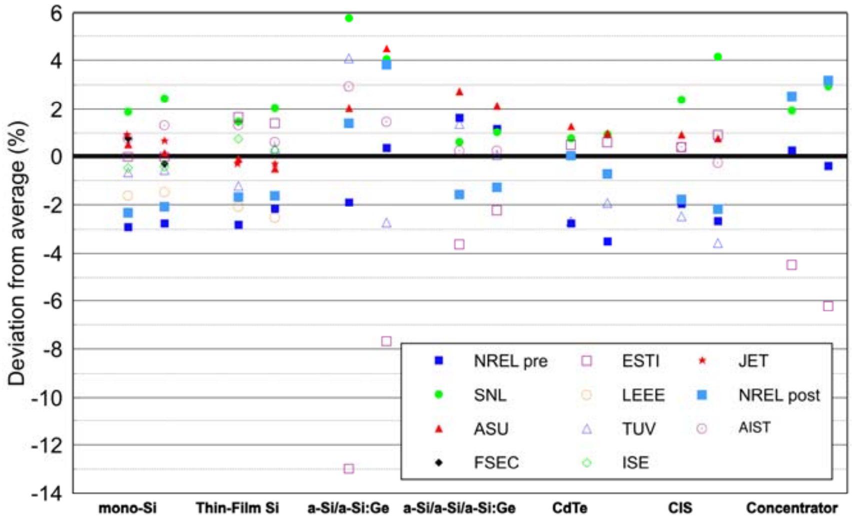
Results - I_{sc} @ 25 C, 1000 Wm^{-2}, IEC Global Reference spectrum



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Summary

- A Variety of measurement artifacts for thin film devices are possible relating to sensitivity to pre-measurement conditions, bias rate, bias direction.
- Effects of short-term transient behavior can be mitigated by light soaking near Pmax for 5 min at 1-sun or longer.
- Metastable behavior has been observed for CdTe, amorphous silicon, and CIGS.
- Calculation of the spectral matching can account for fill factor differences in multi-junction devices once bias rate issues common to pulsed simulators are mitigated.
- Uncertainty in Isc and Pmax are larger for thin-films than crystalline Si as evidenced by intercomparison results.

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Energy Rating
(in the context of thin film modules)

R. Kenny, M. Nikolaeva-Dimitrova, A. Virtuani

European Commission, DG Joint Research Centre,
Institute for Environment and Sustainability,
Renewable Energies Unit, Ispra, Italy

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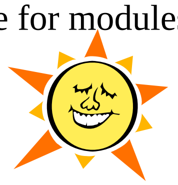
Energy Rating (ENRA)

- Why the need for Energy Rating?
  - Peak power (Wp) at Standard Test Conditions (STC) is currently the standard performance guide for modules
  - But use or get paid for kWh NOT Wp!



- Energy Rating Procedure
  - The performance is measured over a range of irradiances and temperatures to simulate the conditions that will be experienced outdoors
  - Outdoor verification: The module is placed outdoors on the ENRA test rack and continuously monitored for up to one year

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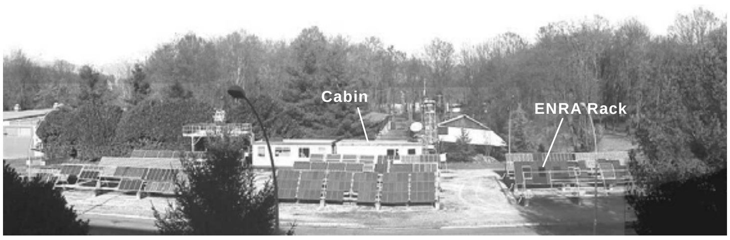
Outdoor Test Field for ENRA



Outdoor photovoltaic test field at ESTI

Rack used to mount the ENRA modules on the outdoor test field

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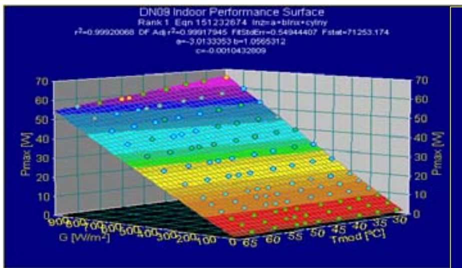
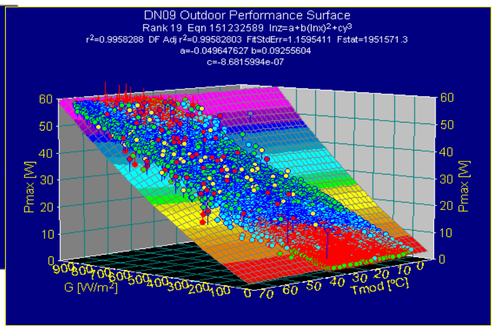
CIS module Performance Surfaces





Indoor Surface Outdoor Surface

Indoor and outdoor measured Performance Surfaces (P_{max} as a function of irradiance and module temperature).

Outdoor values have been seen 10% higher than indoor values.

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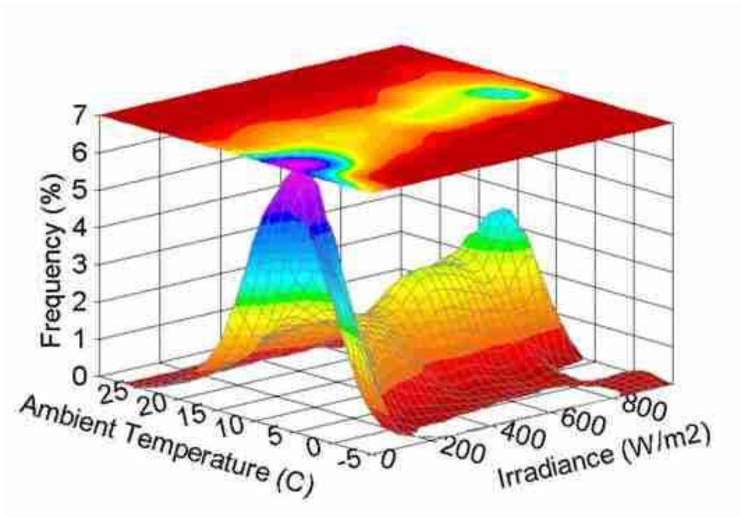
Distribution surface of environmental conditions for one year at Ispra, North Italy.



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Energy Rating Results

- c-Si
  - good match indoor/outdoor power surfaces
  - Good energy prediction
- CIS & a-Si
  - discrepancies indoor/outdoor
  - => Poor energy prediction
  - Need to improve this situation
- IEC 61853 draft (Module Power and Energy Rating) already discussed yesterday

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Measurement issues with thin film modules

- Light soaking necessary to stabilise a-Si.
- During operation performance of a-Si does change (e.g. winter/summer) with combination of light soaking and thermal annealing processes.
- Light soaking of CIS has been found necessary immediately prior (of order of minutes) to measurement on simulator in order to achieve repeatable results.
- Underestimation of power, principally due to underestimation of FF of Cd-Te modules on pulsed simulator, as compared to outdoor measurements

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Study of Spectral effects on outdoor performance

- Explore effect of Solar spectrum
- Mount modules on solar tracker to minimise effects of angle of incidence
- Use ESTI sensor and pyranometer as references
- Measure spectrum with spectroradiometer
- Tested modules:
  - AI01 c-Si (as control)
  - CQ01 a-Si
  - DN09 CIS

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Test configuration on solar tracker

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Mismatch Factor MMF correction

Outdoor Performance Data → MMF Correction → Corrected to AM1.5G ↔ Comparison ↔ Ideal Outdoor data

$$MMF = \frac{\int SR(\lambda)_{DUT} \cdot G_{AM1.5G}(\lambda) \cdot d\lambda}{\int SR(\lambda)_{DUT} \cdot G_{test}(\lambda) \cdot d\lambda} \cdot \frac{\int SR(\lambda)_{\mathrm{Re}\,f} \cdot G_{test}(\lambda) \cdot d\lambda}{\int SR(\lambda)_{\mathrm{Re}\,f} \cdot G_{AM1.5G}(\lambda) \cdot d\lambda}$$

Spectral Response Measurements

Measurements of the Solar Spectra

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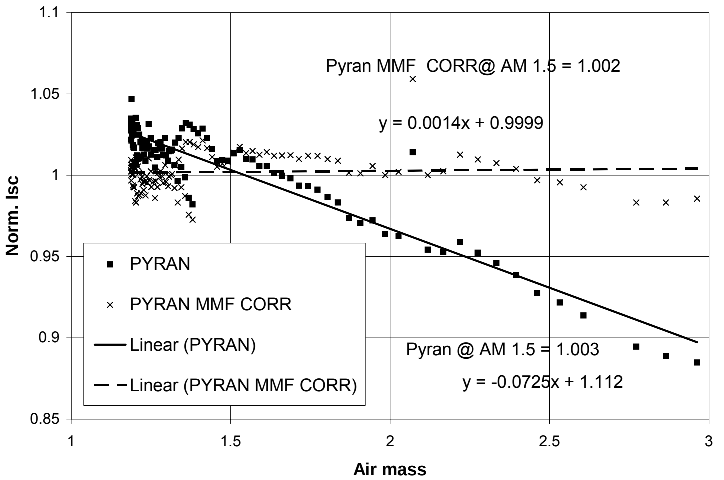
I_{sc} a-Si module with pyranometer reference



The normalised Isc (corrected to STC) is plotted against Air Mass as measured, and corrected for MMF

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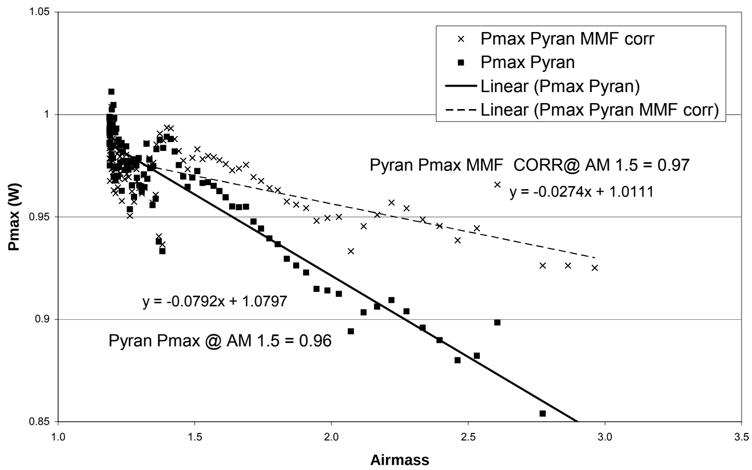
P_{max} a-Si module with pyranometer reference



The normalised P_{max} (corrected to STC by I-V curve correction) is plotted against Air Mass, both as measured and corrected for MMF

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Pre-conditioning CIS by light soaking

- Light soaking experiments
  - 2 different CIS modules examined
  - Different light soaking levels (natural &artificial light)
  - Changes in performance over time
  - Relaxation after light soaking
- Complications arising
  - Module Temperature difficult to maintain at 25°C
  - Curve corrections needed when temperature varies
  - Temperature coefficients can also vary

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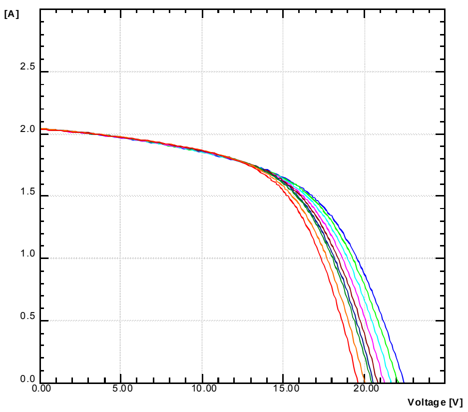
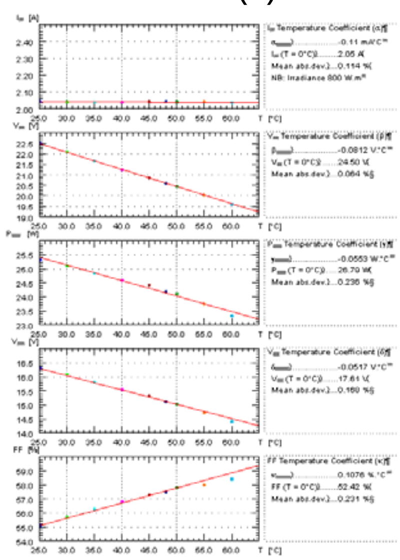
CIS Temperature coefficients (1)



FF +ve coefficient



TCO plots for module IS814 measured as standard
i.e. module kept in dark between flashes

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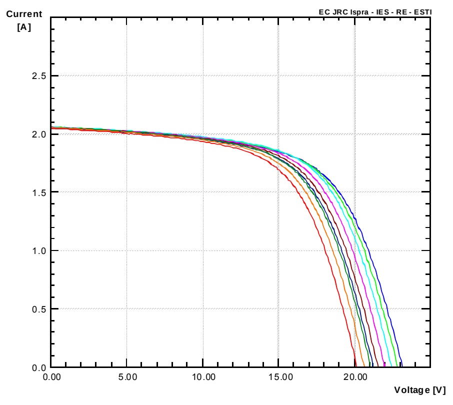
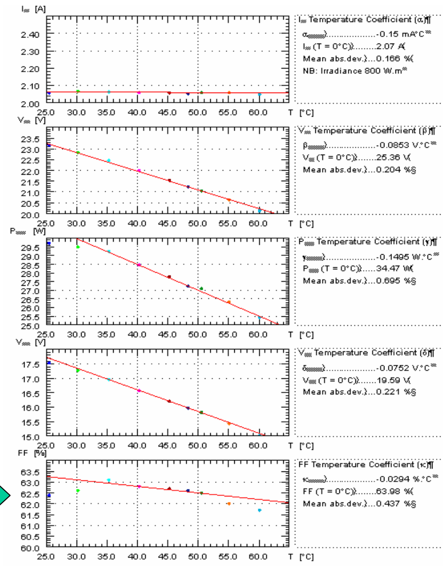
CIS Temperature coefficients (2)



FF increased; -ve coefficient



TCO plots for module IS814 measured with continuous light soaking (approx. level 50W/m²)

CIS Temperature coefficients (3)

Module IS814 Summary	TCO standard [%.°C^{-1}]	TCO bias light [%.°C^{-1}]
Alfa (Isc)	-0.11	-0.15
Beta (Voc)	-0.0812	-0.0853
Gamma (Pmax)	-0.0553	-0.1495
Kappa (FF)	0.1076	-0.0294

TCO measured as normal, and with light soaking (approx. 50W/m²).
Note the change from +ve to –ve in the FF TCO and corresponding increase in Pmax TCO.

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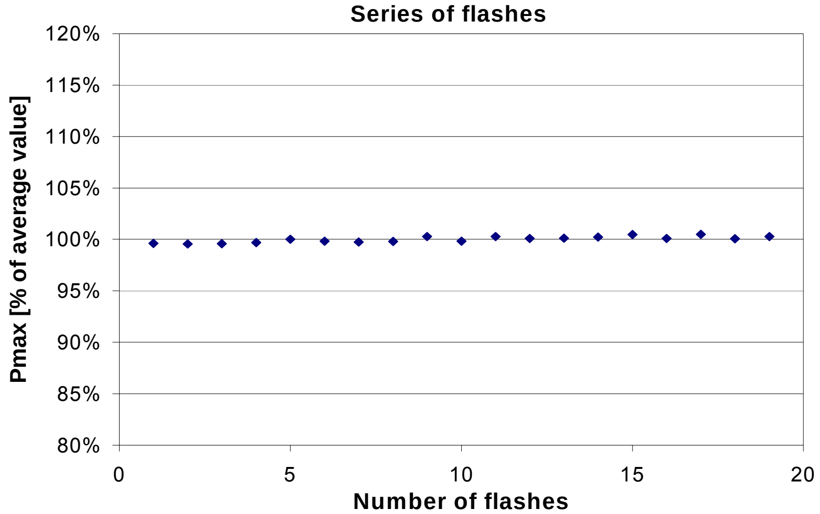
CIS Module IS814 – effect of flashes



Series of flashes made at 30 second intervals. A small increase in Pmax is observed (0.7 % in 19 flashes). Not significantly large to have affected TCO results (which is only 9 flashes, separated by typically 30 mins.)

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CIS Curve Correction

[º C]	$Pmax_1$ at 700[W/m²] at diff. T[º C]	$Pmax_1$ Correction to STC	$Pmax_{1\ corr\ STC}$ / $Pmax_2$ at 1000[W/m²] a t25 ºC	$Pmax_2$ at 1000[W/m²] at diff. Tº C	$Pmax_2$ Correction to STC	$Pmax_{2\ corr\ STC}$ / $Pmax_2$ at 1000[W/m²] a t25 ºC
25	45.66	64.71	1.327%	65.58	65.59	-0.015%
30	45.34	65.66	-0.122%	64.15	65.65	-0.107%
35	44.22	65.51	0.107%	63.14	66.17	-0.900%
40	43.39	65.76	-0.274%	61.50	66.02	-0.671%
45	42.05	65.37	0.320%	59.74	65.78	-0.305%
48	41.19	65.08	0.762%	59.07	66.01	-0.656%
50	40.70	65.00	0.884%	57.93	65.45	0.198%
55	40.13	65.64	-0.091%	56.76	65.75	-0.259%
60	38.75	65.11	0.717%	55.87	66.40	-1.250%

Validation of the temperature and irradiance corrections based on IEC 60891 has been performed for module DN09

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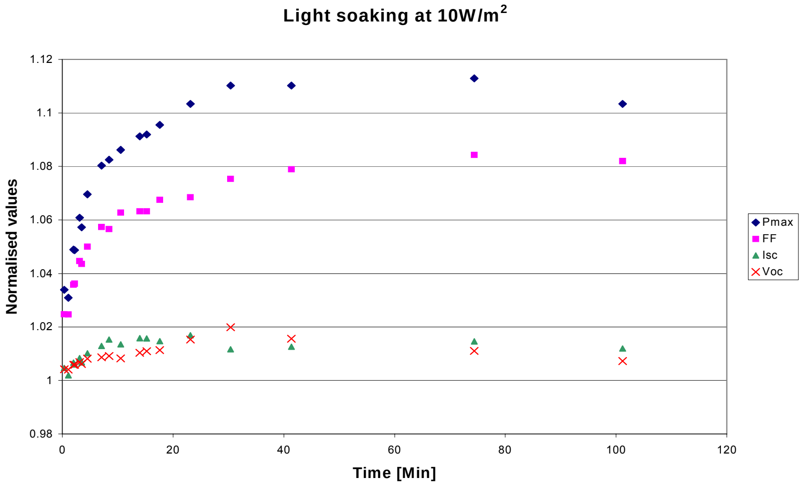
IS814 Light soaking @ $10W/m^2$



Variation in parameters with time of light soaking. The values have been corrected to 25°C (during the light soaking the module heated from 25°C to 26°C due to the heating effect of the lamps).

The maximum obtained Pmax is lower than with a higher light level.

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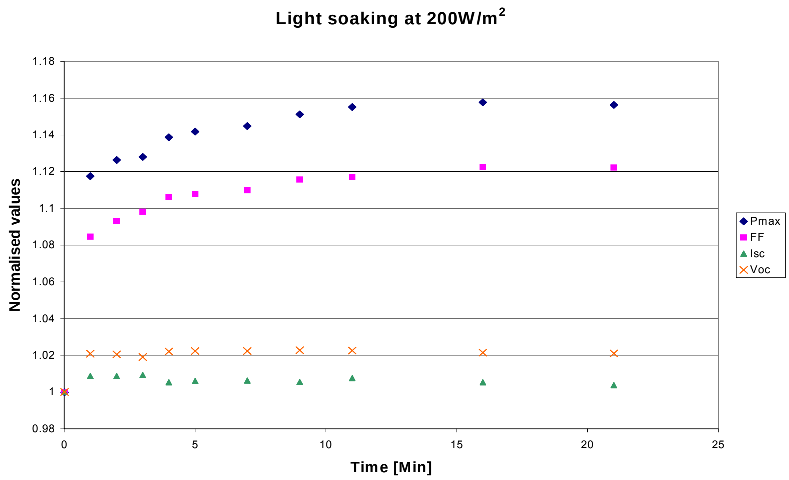
IS814 Light soaking @ $200W/m^2$



The values have been corrected to 25°C (during the light soaking the module heated from 25°C to 39°C).

Clearly the effect is largely a result of improvement in Fill Factor.

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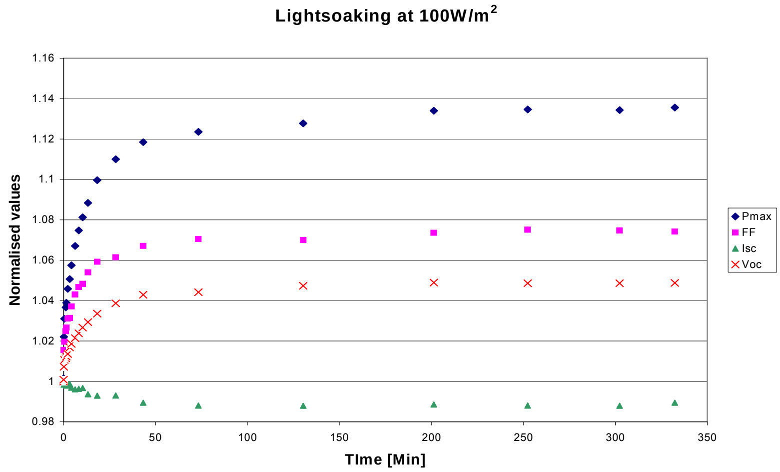
DN09 Light soaking @ 100W/m^2



The values have been corrected to 25°C (during the light soaking the module heated from 25°C to 40.7°C).

For this module the Voc also improves with the light soaking, although the FF improvement is still the most significant.

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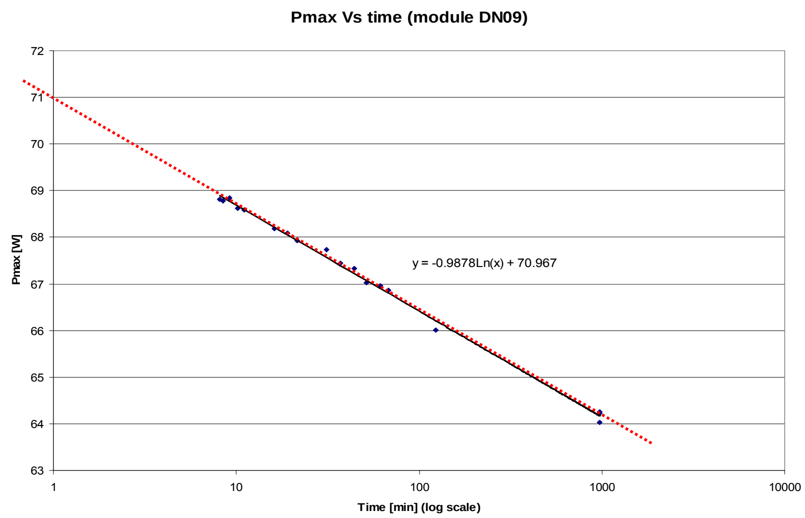
Light soaking relaxation



Typical relaxation over time (log scale). Note that significant degradation already takes place before first measurement after bringing inside (outdoor value 71.5 W).

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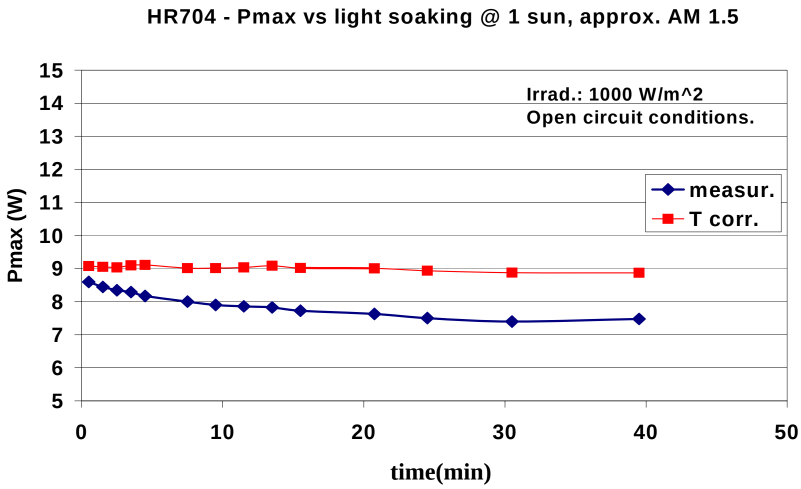
HR703 – Light Soaking Outdoors



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Light soaking - summary

Module	Dark	10W/m²	100W/m²	200W/m²	1000W/m²
DN09	62.93	65.75	67.32		71.50
IS814	33.49	36.91		38.39	39.88
BX81	39.55				49.04

Table summarising maximum obtained Pmax values for 3 modules, depending on light soaking level used.

N.B. The 1000 W/m² value is that obtained outdoors in clear sunlight

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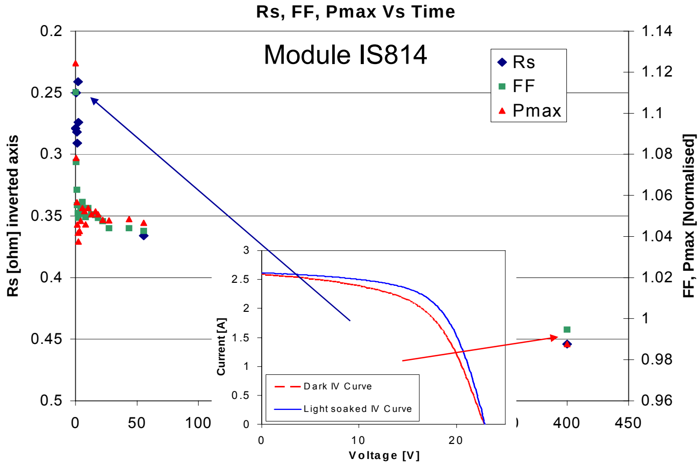
Light soaking – effect on Rs



R_s is calculated from IV curves measured during relaxation and it is found to closely mirror changes in P_{max} and FF.

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CIS Conditioning Conclusions

- Light soaking of CIS modules essential for characterisation
  - Not straightforward to perform
  - Maintaining temperature
  - Light soaking while measuring
  - Fast effect, so relaxation begins immediately light is removed
- Performance improvement depends on light level
  - Maximum obtained
  - Time to reach maximum
- What is the real power at a given condition?
  - power under steady state illumination at the level of interest.
- Light soaking procedures (as per IEC 61646) may not be appropriate/sufficient for these modules

Sweep Time Effects

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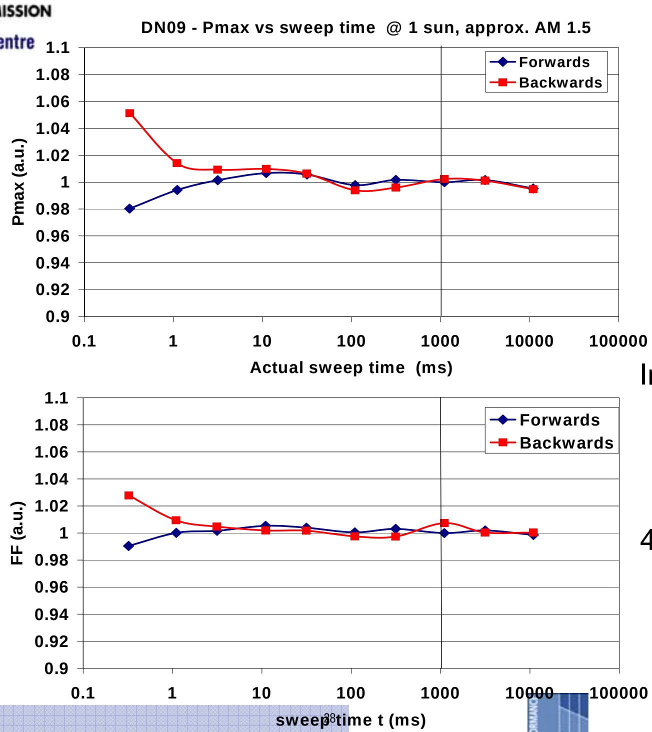
DN09 – Sweep time effects

P_{max}

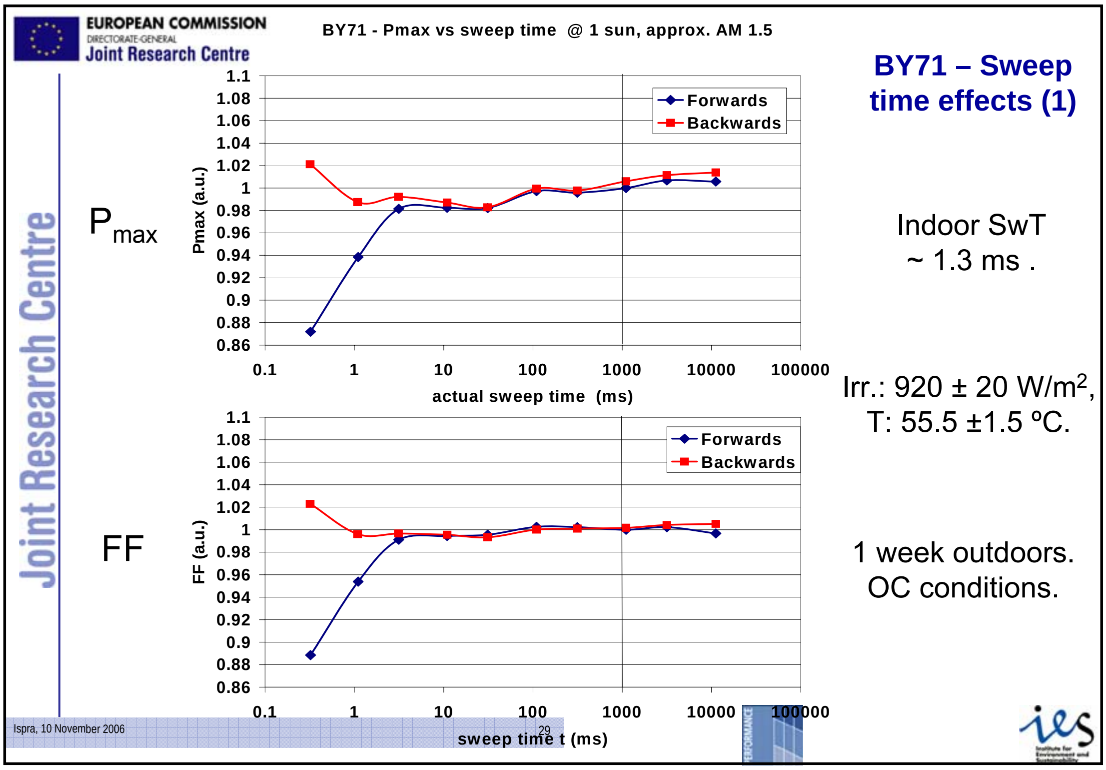
FF



Indoor SwT ~ 0.7 ms .

Irr.: 995 ± 5W/m^2, T: 57 ±1 ºC.

4 days outdoors. OC conditions.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BY71 - Pmax vs sweep time @ 1 sun, approx. AM 1.5
BY71 – Sweep time effects (1)
Pmax
Pmax (a.u.)
Forwards
Backwards
actual sweep time (ms)
Indoor SwT ~ 1.3 ms .
Irr.: 920 ± 20 W/m2, T: 55.5 ±1.5 ºC.
FF
FF (a.u.)
sweep time t (ms)
1 week outdoors. OC conditions.
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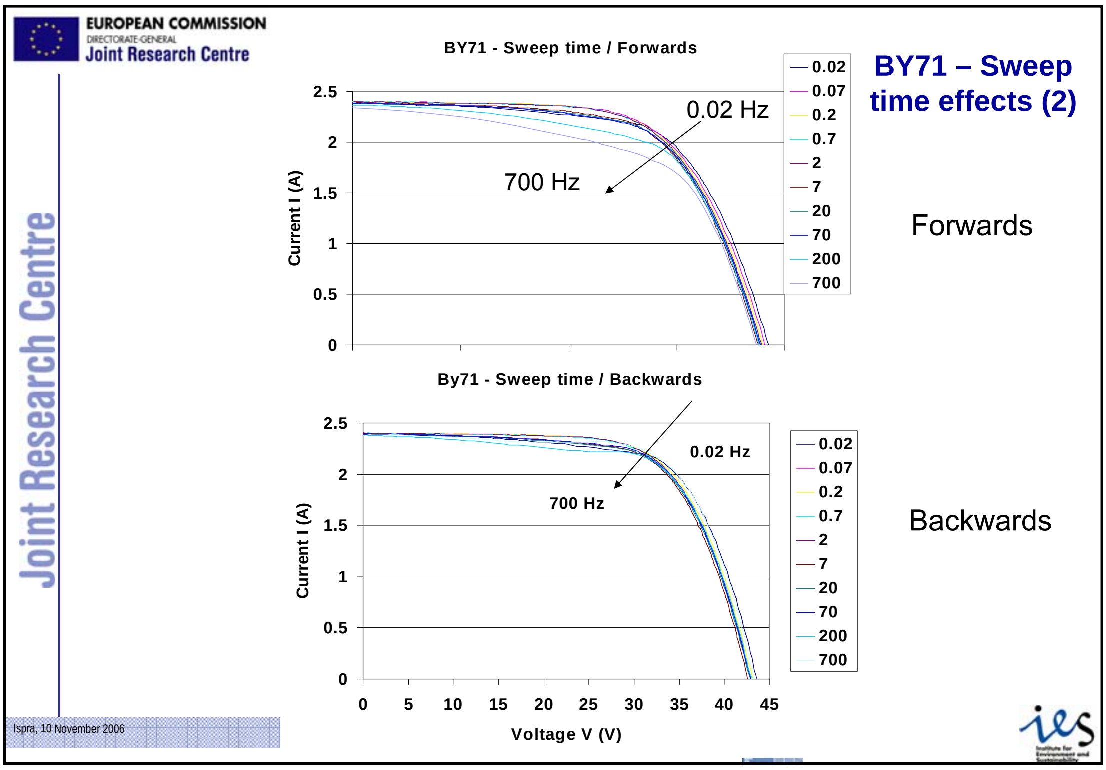
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Joint Research Centre
BY71 - Sweep time / Forwards
BY71 – Sweep time effects (2)
Current I (A)
0.02 Hz
700 Hz
0.02
0.07
0.2
0.7
2
7
20
70
200
700
Forwards
By71 - Sweep time / Backwards
Current I (A)
0.02 Hz
700 Hz
Backwards
Voltage V (V)
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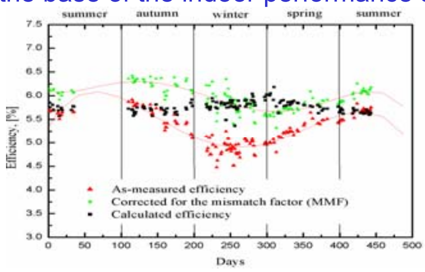
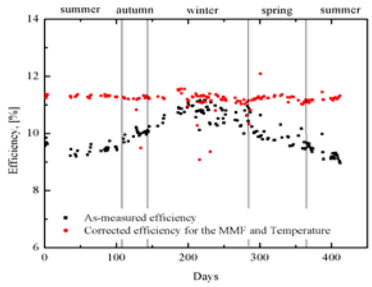
a-Si Outdoor

Outdoor efficiency for one year period 2005-2006. The calculated efficiency is on the base of the indoor performance surface equation from 2002.



The module performance drops during the winter months due to the accumulated light exposure at low temperatures, and improves in the summer months due to the accumulated effects of higher module operating temperature.



Outdoor efficiency for c-Si module; as-measured and corrected using the same procedure as for a-Si module

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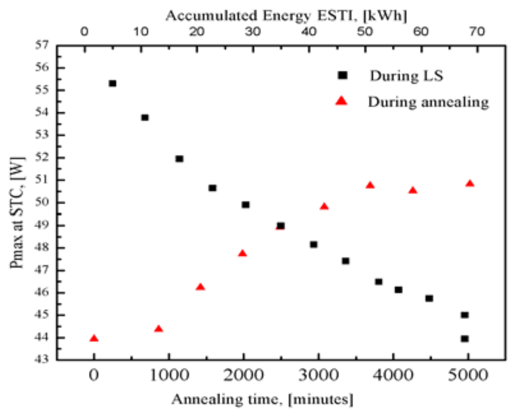
a-Si Controlled module conditioning

- A second a-Si module of the same type has been subjected to controlled light-soaking (LS) and thermal annealing.
- During the LS at Tmod= 18 °C (outdoor) the Pmax decreased to a minimum of 45.0 W at an accumulated energy of 444 kWh.
- During annealing at Tmod = 60 °C (indoor) the Pmax recovered to a maximum of 50.7 W after 83 h of exposure.



Changes of the Pmax: (▪) during LS as a function of the accumulated energy (top scale); (▲) during annealing at 60 °C as a function of annealing time (bottom scale)

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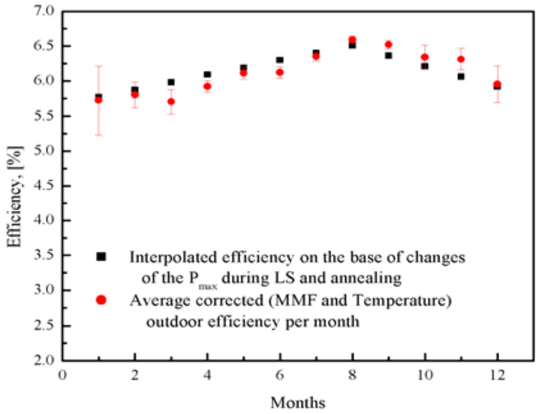
Simple efficiency prediction

- Take extremes of LS and annealing as minimum/maximum.
- Assume a linear progression.
- Compare with monthly averages of outdoor efficiency.



Comparison of the interpolated efficiency from the lineal progression of changes of the Pmax and monthly averages of outdoor efficiency

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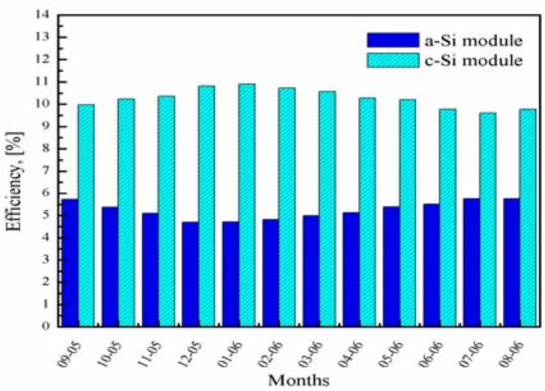
Comparison of a-Si and c-Si performance

- Clearly visible within the c-Si data is the quite severe drop in efficiency in the summer months due to the high module temperatures.
- For the a-Si module however, the efficiency in the summer months is actually greater than the winter months since the improved performance resulting from the thermal annealing more than compensates for the relatively lower temperature coefficient of maximum power.



Measured efficiency [%] per months for one year period – from September 2005 up to August 2006 for a-Si and c-Si modules

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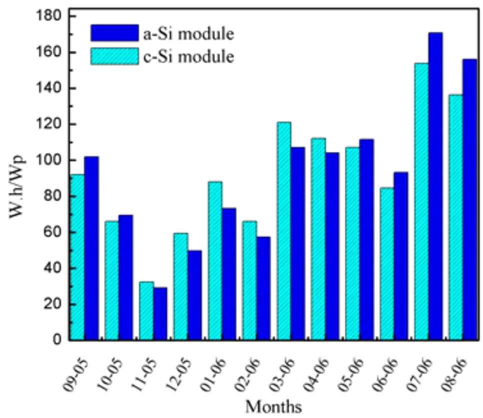
Energy production of a-Si and c-Si modules

- The energy production per watt-peak in summer months is greater for the a-Si module, while it is lower during the rest of the year.
- The result is strongly dependent on actual choice of watt-peak chosen – here we have arbitrarily chosen the mean annual value.
- Note that chosing the highest value for labelling will result in lower Wh/Wp values and vice versa.



Wh/Wp for the same one year period for a-Si and c-Si modules

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Welcome to PERFORMANCE IP

Dr. Ewan Dunlop
European Commission DG JRC

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AIM of The Project

Understanding of

- PV device testing methods
- PV module and system performance
- PV module and system stability

for increased

- - transparency for all market actors
- - confidence and planning reliability

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Approach of the Project

Cover a long section of the value chain:
from cells to systems

Harmonise between labs and industry, provide traceability from power to energy

Cover 9 orders of magnitude in space: from cm shading effects to performance prediction for every place in Europe

Cover 8 orders of magnitude in time: from seconds (e.g. inverter clipping) to life-time effects (ageing)

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Justification

There is much knowledge on measurement and testing procedures as well as PV performance prediction and assessment, but

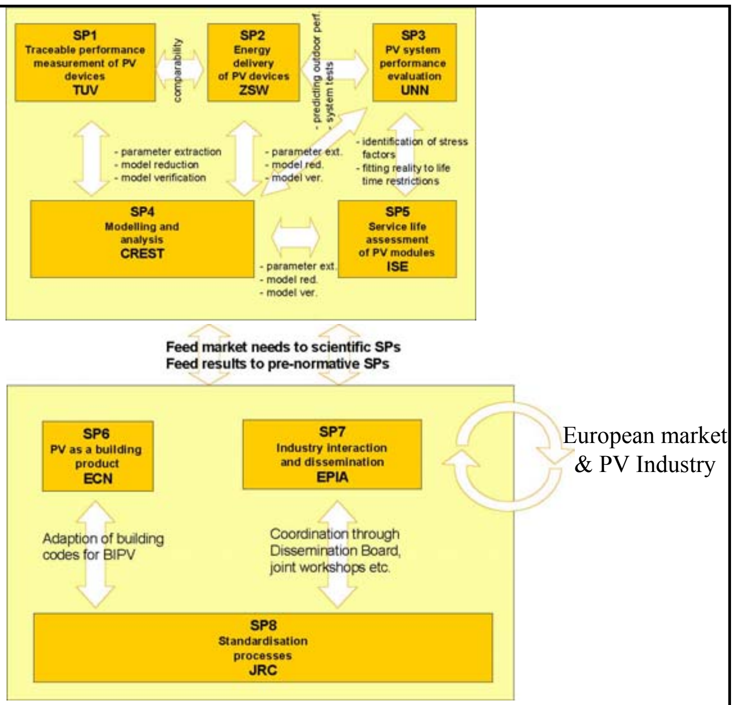
- it is not integrated along the dimensions mentioned
- it is not implemented in real life
- it is not sufficient for industry and market needs in a multi gigawatt market

PERFORMANCE will be a project with a profound and large scientific core, serving the market's need for transparency, confidence and planning reliability

Sub Projects

- 1: Indoor PV device calibration
- 2: Outdoor PV module performance
- 3: PV system performance evaluation
- 4: Modelling and analysis
- 5: Service life assessment of PV modules
- 6: Building integration special issues
- 7: Industry feedback loops
- 8: Standardization process

Project Structure



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Performance Project Data

- Number of partners: 28
- Total costs: 11,810,000 €
- EC contribution: 7,000,000 €
- Project starting date: Jan. 1st, 2006

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Project Partners

Fraunhofer ISE, Freiburg, DE
PSE, Freiburg, DE
EPIA, Brussels, BE
CIEMAT, Madrid, ES
WrUT, Wroclaw, PL
Joint Research Centre, Ispra, IT
TÜV, Cologne, DE
ECN, Petten, NL
CREST, Loughborough University, UK
CEA-GENEC, Cadarache, FR
SUPSI-TISO, Canobbio, CH
UNN-NPAC, Newcastle, UK
ZSW, Stuttgart, DE
Isofotón, Malaga, ES

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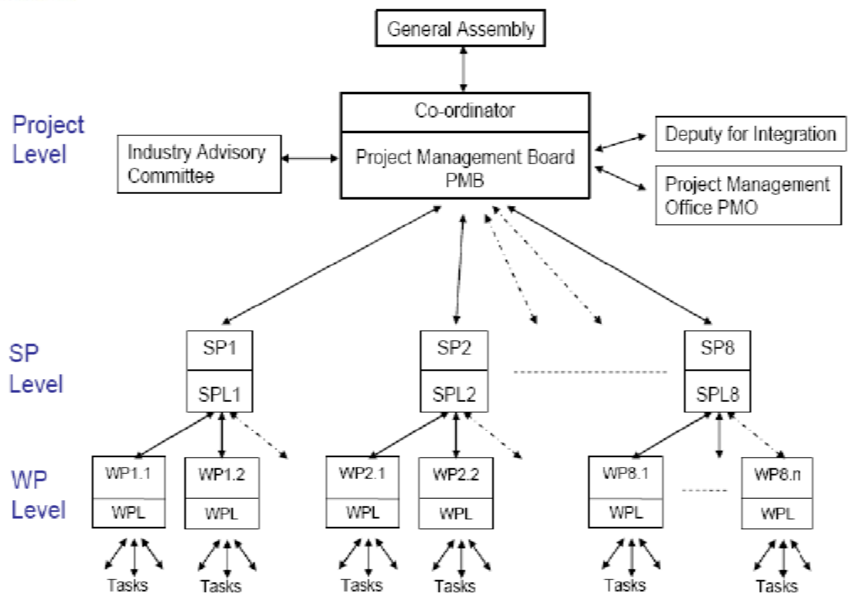
Project Partners

Shell Solar, München, DE
Phönix Sonnenstrom, Sulzemoos, DE
Conergy, Hamburg, DE
RWE Schott Solar, Alzenau, DE
Scheuten Solar Systems, Venlo, NL
Arsenal, Wien, AT
Ben Gurion Univ., Beer Sheva, IL
Tallin Univ., Tallin, EE
MeteoControl, Augsburg, DE
FH Magdeburg, Magdeburg, DE
SP, Boras, SE
PCCL, Leoben, AT
Ecofys, Utrecht, NL
IT Power, Basingstoke, UK



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SP8: Standardisation Process
Objectives

- To obtain from organised meetings, workshops and surveys the understanding of the needs of the market players and stakeholders in the full implementation chain of photovoltaic solar electricity. "**covering the entire spectrum of the performance of photovoltaics in order to improve the competitiveness of European Industry**"
- To create the appropriate communication from the identified needs of the stake holders industries through the research of the technical work packages (WP 1 to WP 6) and convert/interpret this in to an appropriate form for international standardisation, normalisation or guidelines. "**Bring the right people together**"
- To provide the bridge between the international standards bodies and the individual sub projects within this project. The key goal is to communicate between ongoing activities in the standards committees and the activities of the pre-normative research teams in this project to coordinate not only the research of current interest but to guide the introduction of new work proposal to the standards committees. "**Bridge the gap between needs, solutions and standards**"

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What do we need to go forward

- Clear problem areas where the R& D effort can be focused
- Industry survey

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2. Where do you perceive missing or unclear issues where standards norms or guidelines could improve industrial competitiveness and enhance end user confidence?

General area	Specific issue	Example	Comments
e.g. 1. No clear indication for system voltage sizing	Where to target system voltages to improve cross compatibility	Customer wants to include several different power conditioning units	Industry guide or agreement of voltage bands to harmonise power conditioning choices
Eg. 2 Module power in operating condition ,	What is the power in a given mounting integration conditions	System includes , roof integrated open rack and façade elements what is power output expected	Test at present foresee only performance at NOCT open rack , further standard performance data is needed for other installations

Meier Vakuumtechnik GmbH

www.meier-group.com

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Meier Vakuumtechnik GmbH

„Economical Laminating -

Today And Tomorrow“

Lamination - fundamentals

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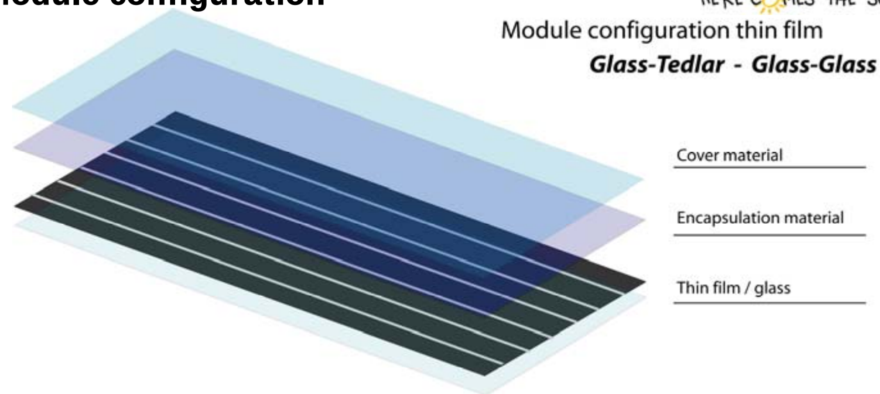
Module configuration



Cover material like:	Glass, polytetrafluoroethylene, polymethyl methacrylate, polycarbonate, polyvinyl fluoride , polyethylene terephthalate
Encapsulation materials like:	Ethylene vinyl acetate copolymer, polyvinyl butyral , Surlyn, thermoplastic polyurethane

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Lamination - fundamentals

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Encapsulation materials

Encapsulation material	Shortcut	Foil-thickness	Processing temperature	Vacuumtime pins up	Vacuumtime pins down	Presstime / forming pressure	Crosslinking-time / -level	Complete-processing-time
		[mm]	[°C]	[min]	[min]	[min] / [mbar]	[min] / [%]	[min]
Ethylene vinyl acetate Normalcure	EVA NC	0,2 bis 1,2	145 to 155	0 to 2 0	0 to 3 up to 5	< 1 / < 1000	15 - 20 / > 75	20 - 25
Ethylene vinyl acetate Fastcure	EVA FC	0,2 bis 1,2	140 to 150	0 to 2 0	0 to 3 up to 5	< 1 / < 1000	7 - 14 / > 75	12 - 19
Ethylene vinyl acetate Ultrafastcure	EVA UFC	0,2 bis 1,2	140 to 155	0 to 2 0	0 to 3 up to 5	< 1 / < 1000	3 - 7 / > 75	7 - 12
Polyvinyl butyral	PVB	0,51 und 0,76	140 to 145	0 to 4 0	0 to 4 up to 8	< 3 / < 1000	< 10 / hold time	< 25
thermoplastic polyurethane	TPU	0,25 bis 0,7	150 to 160	0 to 6 0	0 to 6 up to 6	< 1 / < 1000	2 bis 4 / hold time	10 - 14
Ionomere	SY (Surlyn)	< 0,8	140 to 150	0	0 to 6	< 1 / < 1000	bis 5 / hold time	9 - 13

Average peak addicted to glass thickness / module configuration / module size / plant type etc.

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Bayer MaterialScience etimex jura-plast GmbH film production KSE TROSIFOL

Requirements - plant technology

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Important for the quality and stability of the encapsulation

- Temperature uniformity +/- 2%
- Evacuation time 1mbar < 1 minute
- Final vacuum < 0,5 mbar
- Plane heating plate

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Requirements - plant technology

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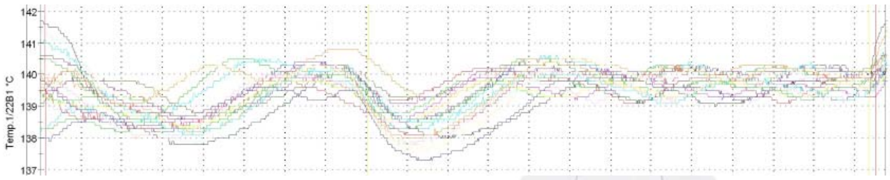
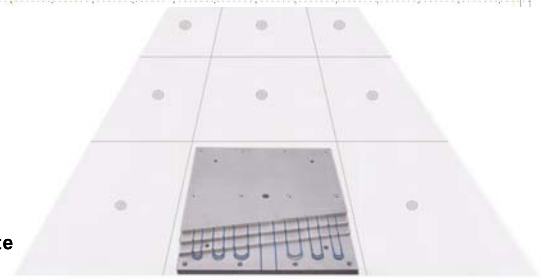
Heating plate layout und temperature-control





Maintenance- and oil free heating plate in separate zones

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Requirements - plant technology

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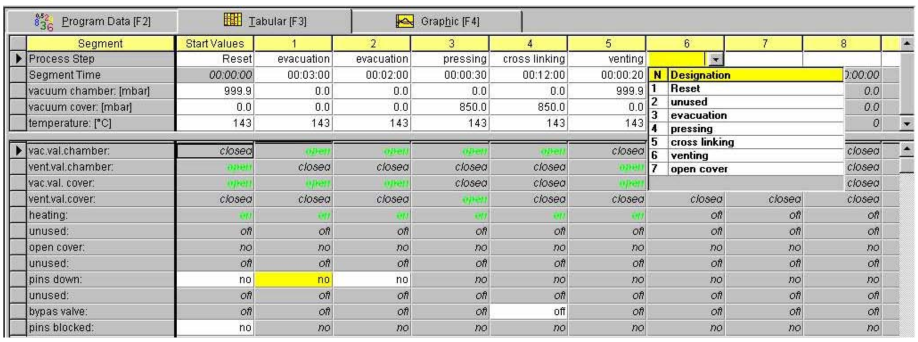
Process parameter and temperature-control



Program Data [F2] | Tabular [F3] | Graphic [F4]

Segment	Start Values	1	2	3	4	5	6	7	8
Process Step	Reset	evacuation	evacuation	pressing	cross linking	venting			
Segment Time	00:00:00	00:03:00	00:02:00	00:00:30	00:12:00	00:00:20			0:00:00
vacuum chamber: [mbar]	999.9	0.0	0.0	0.0	0.0	999.9			0.0
vacuum cover: [mbar]	0.0	0.0	0.0	850.0	850.0	0.0			0.0
temperature: [°C]	143	143	143	143	143	143			0
vac.val.chamber:	closed	open	open	open	open	closed			closed
vent.val.chamber:	open	closed	closed	closed	closed	open			closed
vac.val. cover:	open	open	open	closed	closed	open			closed
vent.val.cover:	closed	closed	closed	open	closed	closed	closed	closed	closed
heating:	on	on	on	on	on	on	off	off	off
unused:	off	off	off	off	off	off	off	off	off
open cover:	no	no	no	no	no	no	no	no	no
unused:	off	off	off	off	off	off	off	off	off
pins down:	no	no	no	no	no	no	no	no	no
unused:	off	off	off	off	off	off	off	off	off
bypas valve:	off	off	off	off	off	off	off	off	off
pins blocked:	no	no	no	no	no	no	no	no	no

N	Designation
1	Reset
2	unused
3	evacuation
4	pressing
5	cross linking
6	venting
7	open cover

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Requirements - plant technology

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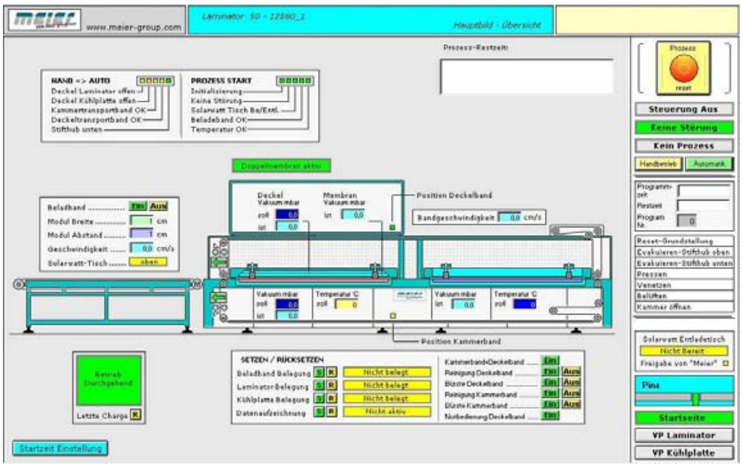
User interface



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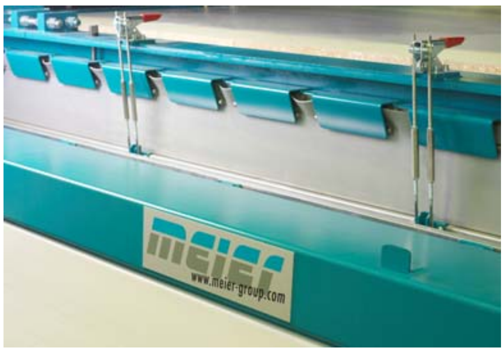
Profitability
Clip-Clamping system

- Extreme short changing time of the process diaphragm < 30 minutes
- „Hole free“ diaphragm
- Initial tension variable and always adjustable



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Requirements - plant technology

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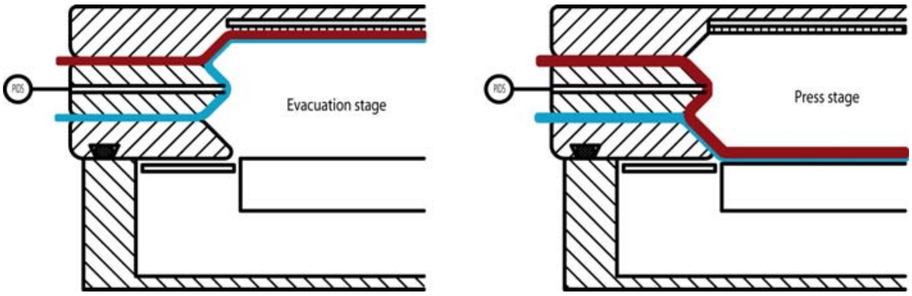
Profitability
Double-Diaphragm system



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Requirements - plant technology

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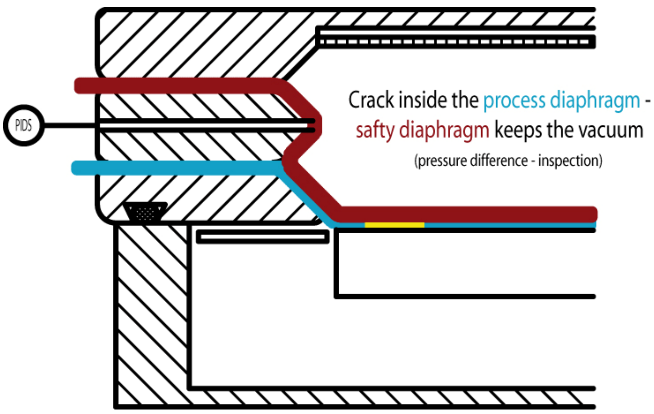
Profitability
Double-Diaphragm system



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Today's production ...

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Manual plant
Type: ICOLAM 28/18
Active surface:
2.700 x 1.700 mm (106 x 67 in)

Fully automatic plant
Type: ICOLAM 46/21
Active surface:
4.500 x 2.000 mm (177,1 x 78,7 in)
Time saving and quality assurance by sideloading

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Tomorrow´s technology...

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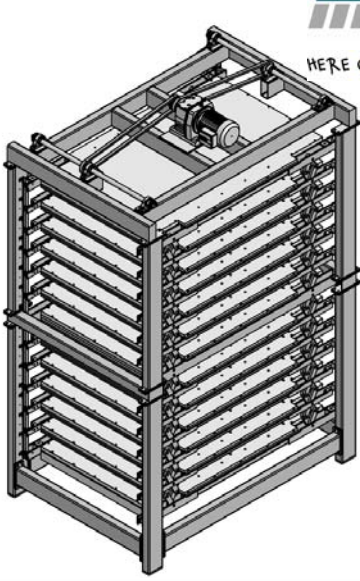
Stack laminator

- 86 % less required footprint
- 75 % less required surface
- 50 % smaller chamber volume
- Thermal coefficient improved
- Best temperature uniformity
- Quick and easy diaphragm frame changing
- Smaller diaphragm, no seams
- Low maintenance costs
- High operational reliability



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Laminating without vacuum

Technical data:

- v: > 0,5 m/min
- Width: > 1000 mm
- Heater power: 2 x 48 kW
- Heating zones: 2 x 3
- No vacuum system
- Uniformity: approx. +/- 2%
- Best temperature in spite of module "bending"

Icolam 1000 *R*

Laminating with thermoplastic polyurethane (TPU)

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Overview - production possibilities

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	4x ICOLAM 36/21	1x ICOLAM 1000 *R*	1x Stacolam 12 E
Footprint [m²]	200	50	30
Radiating surface [m²]	224	Pilot plant	60
Vacuum	Yes	No	Yes
Materials	All	Actually TPU	All
MW*p* / Year	60	45	60

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Leading in vacuum technology

Encapsulation of thin-film

Dr. Patrick Hofer-Noser

3S Leading technology for solar energy

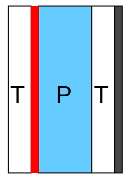
3S –Insulation glas

Skylight with high insulation and shading

Backsheet foils

Fluoropolymer	Abbreviation	Structure
Polyvinyl fluoride	PVF	–[CH2CFH]–
Polyvinylidene fluoride	PVDF	–[CH2CF2]–
Ethylene-terafluoethylene	ETFE	–[CH2CH2]-[CF2CF2]–
Fluorinated	FEP	–$[CF2CF2]_{1-x}$-$[CF2CF(CF3)]_x$
ethylene-propylene		
Perfluoroalkoxy	PFA	–$[CF2CF2]_{1-y}$-$[CF2CF(OR)_y$–
Polychlorotrifluoro ethane	PCTFE	–[CFClCF2]–

Source: [Deb04]



Picture 2: Delamination after 1400 hours aging with PET-SiOx-PET

Source: [Ple04]

ETFE is combined with SiOx barrier. But these modules seem to show delamination between the backsheet and EVA after dampheat tests [Ple04].

Encapsulation foils

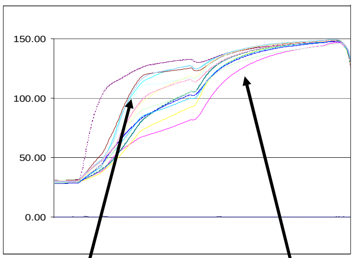
Temperature → hold (duroplastic materials, EVA)

Temperature → reach (thermoplastic, PVB)

Demands on encapsulation process

- Good bonding strength to glass and cell
- No reaction with the cell surface
- Controllable and repeatable process conditions
- No trapped air within the laminate
- Short cycle time

Lamination process, real, what can happen



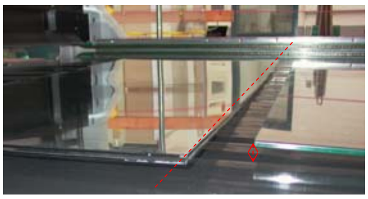
Warping region

Inhomogeneous temperature distribution

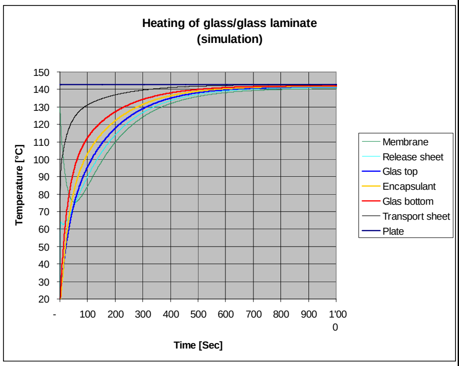
Warping of glass

Reasons

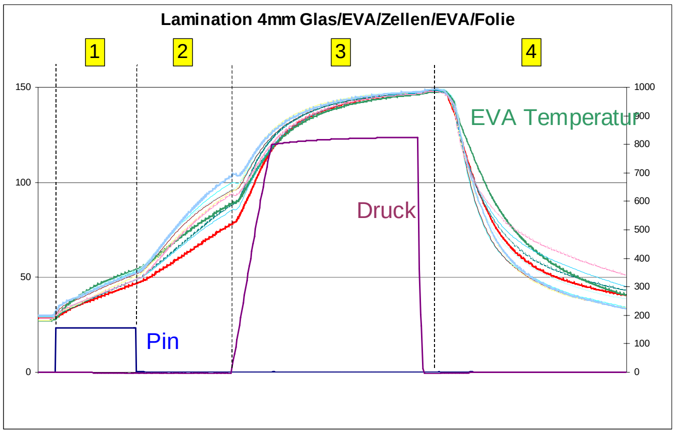
- Inhomogeneous temperature of the glass in horizontal plane
- temperature gradient in vertical direction (especially in glass/glass laminates, but also in single glass)



warping of glass:



Lamination process, real with hybrid heating system and pin-lift



1 Evacuate
2 Heat up
3 Press/unload
4 Cool/unload

Laminators 3621CP

Laminator for heavy double glass modules

3S laminator S2821 with
hybrid heating plate and with cooling press

Photovoltaics

Photovoltaics

Future trends for thin-film ?

- Optimized processes and materials
- Larger sizes of machines or smaller inline systems
- VSG processes (autoclave)

- Non vacuum processes depending on the processes Superstrat or Substrat technology

Risk analysis
Part of the lamination in the overall TF production

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for Solar Energy

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EUR 22630 EN – DG Joint Research Centre, Institute for Environment and Sustainability
Luxembourg: Office for Official Publications of the European Communities
2007 – 155 pp. – 21 × 29.5 cm
EUR - Scientific and Technical Research Series; ISSN 1018-5593